Iron and Steel Engineer

Established 1907 as Proceedings of A. I. & S. E. E.

J. F. KELLY, Editor

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Vol. V. August, 1928 No. VIII.

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Published Monthly by

Association of Iron and Steel Electrical Engineers

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Entered as second-class matter January 25th, 1924, at Pittsburgh, Pa., under the Act of March 3rd, 1879.
Subscription Price $5.00 per Year. Single Copy 50c.

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EDITORIAL

THE APPLICATION OF ANTI-FRICTION BEARINGS TO ROLL AND PINION NECKS

By D. M. PETTY*

Early in March a questionnaire was mailed to all of the various steel plants in order to ascertain the present status and feelings of the various steel mill engineers concerning the application of anti-friction bearings to roll and pinion necks. In some cases, each individual plant returned a questionnaire and in other cases, the various plants of one company consolidated their answers into one (1) questionnaire. Altogether ten (10) questionnaires properly filled out were considered. Those questionnaires, however, represented a total of at least 20 plants and in view of the fact that the answers in most cases represented a joint opinion of at least two or three men, it may be said that the tabulations showing the various answers to the questionnaire represent the average opinion of at least fifty (50) steel mill engineers, and it goes without saying that these fifty men are the best informed, as well as the most progressive engineers in the industry. For this reason therefore, this report should point out a few rather definite points in connection with this subject.

It should be especially noted that most of the answers to this questionnaire represent the opinion of these various steel mill engineers rather than the actual experience of these men, because with very few exceptions, almost no experience has been obtained with the use of anti-friction bearings in rolling mills, however, it is in the formative stages of the art and free discussion will do the most good.

It will be noted that in some cases there are more than ten (10) answers to a single question. This is due to the fact that several men gave more than one answer to a question.

Question No. 1.	What do you consider the chief limitation to the use of roller bearings for this service?	
Answers:	Inability to reduce diameter of roll necks	1
	Limits roll dressing	2
	Limitations in bearing design	2
	Mental inertia	1
	Space on old mills	4
	Difficulty of keeping dirt out of bearing	1
	Cost of installing on new mills	1
Question No. 2.	What disadvantages can you suggest in regard to such application?	
Answers:	Inability to take end thrust	2
	Inability to obtain full life out of rolls on small three-high shape mills	1
	Increase neck breakage due to unequal temperature	1
	Increase time of roll changes	3
	None	4
Question No. 3.	Roller bearings, consequently roll necks, can be cooled to about 250° by an oil circulation system on the bearings. Do you think such cooling would tend to cause neck breakage, particularly in the case of hot sheet mill rolls?	
Answers:	Plate Mills and Hot Sheet Mills—Yes	7
	No	1
	Other Mills—No	3
	Yes	0
	No answer	1
	Oil cooling system too complicated	1
Question No. 4-A.	Will the fact that there is practically no wear on roller bearings, either transverse or longitudinal, eliminate any trouble in mill operation?	
Answers:	Yes	10
	No	0
Question No. 4-B.	Will the elimination of wear both transverse and longitudinal in roll neck bearings prove to be or value to mill operation?	
Answers:	Yes	10
	No	0
Question No. 4-C.	Will it help to roll more accurate products?	
Answers:	Yes	9
	No	1
Question No. 4-D.	Will it lengthen the time between roll dressings?	
Answers:	Yes	3
	Doubtful	2
	No	5
Question No. 5.	Have you ever made temperature tests on roll necks after a steady run of the mill?	
Answers:	No	10
	Yes	1
Question No. 6.	If so, will you please give the results?	
Answers:	One (1) Yes to Question No. 5 comments that studies produced such wide variations in results that no safe conclusions of a general nature could be drawn from them.	

*Elec. Supt., Bethlehem Steel Co., Bethlehem, Pa.

BACK-LASH

Back-lash presents quite a problem because its elimination by means of drags would materially reduce the power savings due to the use of anti-friction bearings.

Question No. 7.	Have you experienced any trouble from this source in the use of roller bearings?	
Answers:	Yes	0
	No comments	10
	No	0
Question No. 8.	If so, how was it corrected?	
Answers:	No comment	10
Question No. 9.	Do you think the ordinary coupling box fits will cause serious back-lash?	
Answers:	Yes	4
	No comment	2
	No	1
	Depends on kind of mill and work	4
Question No. 10-A.	If so, would finishing wobblers and coupling boxes remedy the trouble?	
Answers:	Yes	0
	No comment	3
	No	2
	Help, but not cure	5
Question No. 10-B.	What clearance would you use for such fits?	
Answers:	1/8"	5
	1/2"	1
	1/16"	2
Question No. 10-C.	Would the life of the finished surfaces be long enough to warrant the expense?	
Answers:	Yes	2
	No	6
Question No. 11.	Would you prefer universal couplings to finished boxes and wobblers?	
Answers:	Yes	8
	No	1
	Small Bar Mills—No	3

NECKS

With the present practice in regard to the diameter of roll necks, it is frequently found impossible to apply roller bearings to two and three-high stands. To attempt to determine whether or not neck diameters could be reduced to permit the use of roller bearings without danger of neck breakage, your experience or opinions are requested in regard to the following:

Question No. 12.	What are the chief causes of neck breakage?	
Answers:	Heat cracks	8
	Mis-alignment	1
	Bending	3
	Shocks	1
	Poor lubrication	4
	Defects in rolls	2
	Improper design	1
	End thrust that wears away fillet	1
	Necks too small	1
Question No. 13.	Is there any standard ratio between roll and neck sizes for various roll diameters?	
Answers:	Depends on type of mill	3
	Yes	2
	No	5
Question No. 14.	Is the present diameter of necks in proportion to that of the rolls necessary to obtain torsional strength in the necks, or is it to minimize the unit pressure on the bearings?	
Answers:	Present necks are oversize	3
	To minimize bearing pressure	6
	Torsional strength	3
	To limit heating and cooling strains	1
Question No. 15.	If power required for rolling can be reduced from 40% to 50% by the use of roller bearings, and if present neck diameters were necessary either for reason of torsional strength, or to obtain low unit bearing pressure, can neck diameters be safely reduced if roller bearings are used?	
Answers:	Yes	6
	No	2
	Except hot plate and sheet and tin mills	2
Question No. 16.	To what extent would such reduction be limited by the necessary diameter of the wobbler?	
Answers:	None	10
Question No. 17.	What effect does the radius of the fillet between neck and body have on the strength of the former?	
Answers:	Apparently none.	
	It does effect strength of roll and prevents neck from breaking close to body.	
Question No. 18.	What rule do you use to determine the radius of this fillet?	
Answers:	Big as possible	3
	No comment	3
	No rule	3
	Taper radius	1
Question No. 19.	The point of application of roller bearing is closer to the body of the roll than in the case of standard bearings. Will this fact allow of a reduction in the diameter of the neck, and still maintain the desired strength?	
Answers:	Yes	7
	No comment	2
	No	1

From the general tone of the replies to the above questions we may deduce the following general conclusions:

1. Steel mill engineers are interested in the application of anti-friction bearings to rolling mills.
2. Roll necks in general can be reduced if anti-friction bearings are applied.
3. The prevention of dirt working its way into the bearings is one of the most serious problems.
4. Proper lubrication of the bearings must be worked out in a simple yet reliable manner.

(Continued on page 392)

*Arc Welding is Selling Steel**

By JOHN LINCOLN†

IRON is used in industry today in two principal forms—first, as cast iron in enormous amounts by the various gray iron foundries in the country, and secondly, as steel produced in the great rolling mills of the country and consuming an increasing proportion of the amount of iron used.

Arc welding is an art which is very young. It was practiced in a very limited way about eighteen years ago, was first heard of through the technical journals by a limited public in the Fall of 1914 when the interned German ships' cylinders were repaired by this method. Since that time the use of arc welding for repairs and maintenance has grown by leaps and bounds, and at the present time the use of this method for repairs in steam railroad shops throughout the country saves millions of dollars per year. I presume the same statement can be conservatively made with reference to the use of arc welding in repairs and maintenance in the steel mills of the country.

More recently the use of welding for the construction of tanks, pressure vessels, and steam pressure pipe, has become quite general and is destined to be the only method which will be used within a few years for this work.

This paper has to deal however, with the application of arc welding to a new field which the author believes is of greater importance than the two previously mentioned uses combined, and which will greatly increase the use of rolled steel shapes and correspondingly decrease the use of gray iron castings. To those who are not acquainted with the possibilities of arc welding in the manufacture of machinery, this statement will sound unreasonable and exaggerated, but the experience of the company with which the author is connected, makes it safe to say that what has been accomplished in the product manufactured by this company by arc welding can be, and very shortly will be, accomplished by other electric manufacturing companies, and by all other organizations fabricating steel which will use the process with a great saving in the cost of manufacture of their product.

During the last fifteen years the entire line of machinery manufactured by the company with which the author is connected, has been changed from the usual cast construction, which has been used from the time that motors were first built, to the welded steel construction. Results from all points of view, that is, first cost, effect on the customer, effect on the factory organization, are fully known at the present time. Work has been done over this period of time slowly and every step has been thoroughly proved. Since there was no previous practice along this line to go on, every step has been necessarily a pioneering step and the difficulties, dangers, advantages, and effects of this construction have necessarily been worked out during this period.

The experience, methods, and data which have been developed by the author's company during this period of development, would make it possible for any other manufacturer to produce similar results in a fraction of the time, and the process has already been put into use by the competitors of the author's company with savings which are enormous, although the application in the case of these competitors has only been very partially made so far. The result of its general application which of necessity must come because of economic pressure, will make the savings in this country alone in excess of $150,000,000 annually in its application to the change-over of cast iron only.

Prefactors of Rolled Steel and Cast Iron

The tensile strength of rolled steel is four to five times as great as that of gray iron castings. The stiffness, or the so-called Young's modulus, is very much greater for rolled steel than for cast iron, yet the cost per pound of rolled steel is about one-third, on an average the cost of castings. This

FIG. 1

means that if a structure is to be built whose utility depends on the tensile strength of its parts, the cost of the material will be from one-twelfth to one-fifteenth as great if structural steel is used of what it would be if castings were used for the same purpose. Furthermore, the chance for breakage from shock of a part made up from structural steel parts by welding, is very much less than the chance for breakage of the same part made up from castings. In fact, the cross section of many cast parts is determined to a great extent by the expected resistance of this section to shock and breakage, which accounts in a great degree for the very much greater weight of castings for a given part as compared with rolled steel welded for the same part.

As stated above, the weight of a part made up of structural steel welded is from one-fifth to one-

*Presented before Cleveland District Section, A.I.&S.E.E., April 20, 1928.

†President, Lincoln Electric Co., Cleveland, O.

fifteenth the weight of the corresponding part made from casting. The saving in cost of the finished part however, is not so great as this because the welding has to be done and in some cases there is preparation of the rolled steel parts to be done before they are welded.

The pictures which are shown herewith will demonstrate that the total cost of the rolled steel structure welded as compared with the corresponding cast structure, is from three-fourth to one-fifth the cost of the corresponding cast structure. This does not mean that all structures will eventually be made from rolled steel welded, but I think it is a safe statement that at least 75% of the castings which are used now can be replaced by welded steel structures at a saving in cost. The saving in first cost however, is not the only advantage to a manufacturing concern of the use of this method—a number of others are almost equally important:

FIG. 2.

First: Less inventory is carried because it is self-evident that the cost of structural steel to produce a certain amount of finished product will be but a fraction as great as the inventory to manufacture the same parts from castings, both because of the less cost of the raw material, and also because of the fact that the structural steel carried in stock would be applicable to many parts while a separate casting was to be made for each part.

Second: There is no scrap in the case of welded steel since if a mistake is made the part is merely re-welded and re-machined.

Third: There is less freight cost in both the incoming and outgoing shipments. This is evident since from one-third to one-fifth of the amount of material is used for the same results.

Fourth: It is easier to make up special designs. It is evident that in making a new machine from castings that complete pattern equipment must be first made up. This is expensive and takes a very considerable amount of time. Furthermore, in special designs the cost of pattern in many cases cannot be capitalized because the pattern will never be used again.

Fifth: The cost of making the drawings is somewhat less for welded structures than for castings because one organization handles the whole job with structural steel shapes welded, where if castings are used the drawings must go to an outside organization.

Sixth: Very much quicker delivery of new or special design. It is clear that a manufacturer making his product from structural steel shapes welded does not have the delay incident to the making of drawings for patterns, the making of the patterns, the making of castings. Therefore, the manufacturer making a special design from structural steel welded can make deliveries in from one-half to one-fourth the time that the manufacturer using cast iron parts could deliver the same new design made from castings.

Seventh: There is no breakage. The welded structural steel parts will not break, but a long, sad experience shows this same statement is not true of parts made from castings.

Eighth: There is less storage expense since the steel can be stored in very much less space and also less quantities, for reasons that are very evident.

The question naturally arises if there are all these advantages with this method of manufacture why has it not been generally adopted? The answer is that there are a number of very real objections which must be overcome before full advantage can be taken of the new method, and these are chiefly the following:

The appearance of the part made from structural steel welded is different from the appearance of the same part made from cast iron, and therefore, to those who are not used to it, it is objectionable. What we are used to, looks all right, and what we are not used to, is objectionable.

FIG. 3.

Some ten years ago the author took a trip through some of the Central American countries and on this trip visited Guatemala City, the capitol of Guatemala. This Central American country is probably the most progressive of the five Central American States, and Guatemala City is quite a modern town. In a public park of this city a number of marble statues have been erected and of course in the most prominent locations in the park.

These statues are of ladies attired in the fashions of 1895. I know of no better way to get a laugh from this audience than to throw a picture of these statues on the screen if I had one, yet the same figures which would make a laugh now if shown were the height of fashion when these statues were placed in the park. Is it not reasonable to suppose that our notions of what a finished part should look like may not change as radically as our notions of what looks well in dress have changed in the last twenty-five years? It is a rule which seems to me based on very sound reason that any part which is so designed as to do its work in the most effective and economical way, looks well. If this criterion is applied to the appearance of the parts made from structural steel welded, the appearance will be entirely satisfactory. The appearance of the welded structures to the people in the organization of the company with which the author is connected, is usual now and entirely satisfactory.

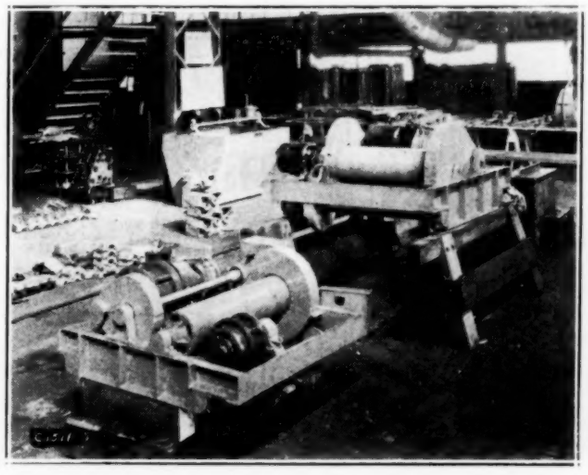

FIG. 4.

When we consider that the curves and fillets of the castings in general are not the result of desire on the part of the designer to make them that way in many cases, but are the result of foundry practice which makes it necessary for castings to be made that way so that they can be drawn from the mould, our point of view in connection with beauty may have to be revised. Structural shapes made into a bridge or a building are beautiful and are so recognized by all of us. If castings with their rounded corners were substituted in these structures, they would not be beautiful, first, because we are not used to them, and secondly, because castings in these structures would not be the best design to produce the desired result.

The second objection is that generally the welded steel design has a very much smaller cross section than the corresponding cast design, and it is impossible for the average person to get away from the idea that the casting is much stiffer and more rigid than the welded steel parts.

As stated above, due to the very much greater tensile strength of steel as compared with cast iron, the part made from structural steel welded, will ordinarily be stiffer than the corresponding part made from castings.

As a matter of fact, in the development of the all-steel welded motor now built by the concern with which the author is connected, the use of the angle iron rings on the stator was almost forced on us on account of the fact that it was impossible to get castings rigid enough to stand the riveting strains which we wanted to impose on the cast iron end rings in order to make a rigid stator without breaking the cast iron end rings. Since the change has been made from cast iron end rings to welded steel end rings, the pressure on the stator end rings before the riveting was done, has been increased about three to one.

The chief reason why the arc welding method of constructing parts of rolled steel has not been more generally adopted, is the inertia that prevents most

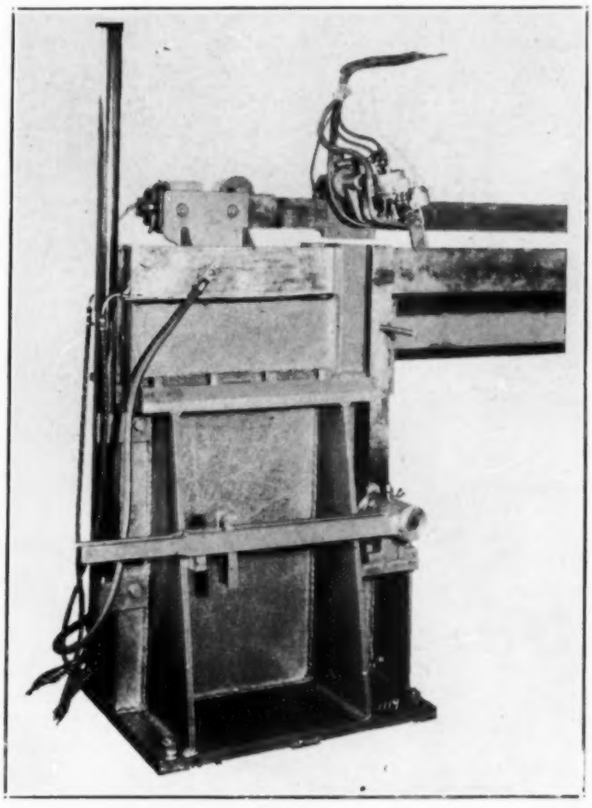

FIG. 5.

of us from adopting something which is new and different from that with which we have been accustomed. It is certain that more of the manufacturers of this country will be forced to this method of construction by competition than will appreciate its advantages and adopt this method of construction on account of its savings. High speed steel came into general use because manufacturers had to adopt the new steel or go out of business, because the use of high speed steel cut the cost of manufacturing to such a great extent. The use of arc welding in the construction of parts is, as I see it, about where the use of high speed steel for tools was five years after Taylor developed high speed steel for cutting tools.

Another objection to the adoption of any new method is that the organization that is going to use the new method will have to become acquainted

with it, with its possibilities, and its limitations, and this is a real objection to its introduction in any organization even though the executives may be convinced that the new method will eventually have to be adopted.

In general, the way to start the introduction of this new method is to take some few parts, perhaps only one part which is giving trouble because of difficulty in machining or service, and change it over to arc welding. After this, other parts will suggest themselves as being proper for redesign. In this way the whole line of parts can be redesigned. This process is what we call "becoming welding-minded." Welding should be thought of

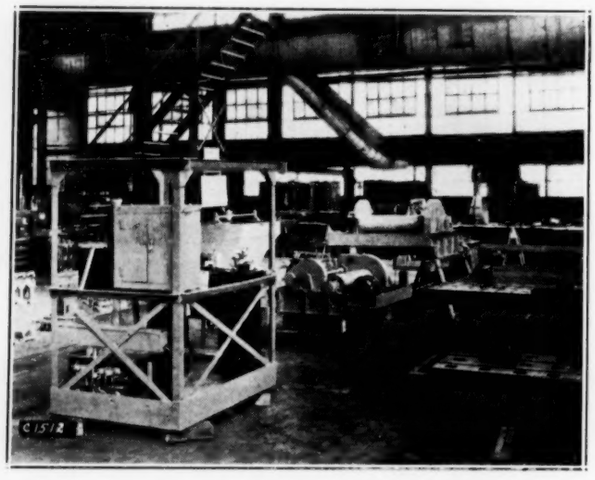

FIG. 6.

as a new tool of great assistance to the manufacturer—not as an upheaval which will change all methods in doing this work.

Nothing has been said so far of the comparison between the riveted and welded structures. In this case the fundamentals are as follows: A single lap riveted joint has an average strength of 50% of the sheet joined—a double lap riveted joint has a strength of approximately 70% of the sheet joined —it is impossible to make a riveted joint as strong as the metals joined. In general, the cost of producing a structure by welding is less than the cost of producing the same structure by riveting. A railroad bridge recently erected in Massachusetts used eighty tons of steel, where the corresponding riveted structure would have called for one hundred and twenty tons.

A number of structural steel buildings have been erected within the last few years by welding instead of riveting. After these structures have had the test of time for a few years, industry will accept the savings which welding makes possible and the welding process will be used in replacing riveting where it can be done with a saving in the resulting total cost.

Another item which has not been touched on is automatic arc welding. Automatic arc welding is applicable in many cases where duplicate structures are produced in quantity. The cost of automatic arc welding in most cases is from one-fifth to one-half the cost of doing the same work by hand. At the same time the work is more uniform and in general has better appearance. The use of automatic welding will, of course, tend to very greatly reduce the cost of welded structures as compared with the method used generally at the present time of hand welding, or to put it another way, the use of automatic arc welding will tend to still further reduce the cost of parts made from structural steel by arc welding as compared with the same parts made from castings.

It is evident that this manufacturing method will be adopted universally within a comparatively short time. It is as sure to come as the turbine was in displacing the reciprocating engine; as the steam ship to replace the sailing ship; of the machine gun to replace the rifle; of high speed steel to replace common tool steel; of the automobile to replace the horse.

It is also self-evident that the manufacturer who first adopts this method and develops it, will reap the greatest advantage. As an average, it is safe to say that any manufacturer who is now making machinery of any kind from castings can save at least 20% of his present cost by going to this new method.

In a few years the application will become so general that those who do not do it must of necessity be forced out of business, and those who do it at that time will only be meeting the methods already adopted by their competitors and, therefore, the use of the new method will not save them anything as compared with costs as there will be at that time.

It has been said that successful manufacturing consists of a state of mind—any manufacturer who adopts the attitude that manufacturing methods are

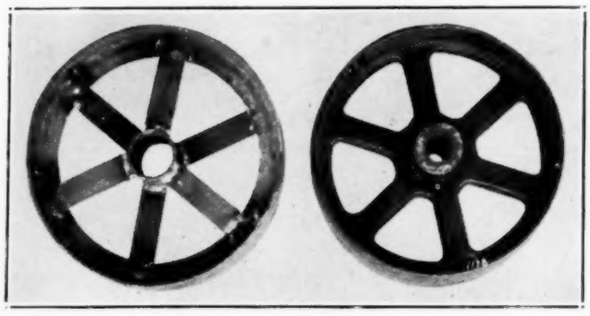

FIG. 7.

any more than a temporary makeshift, is doomed to failure. The successful manufacturer is the manufacturer who is able to adopt new processes and methods first, in other words, he must adopt the point of view that every manufacturing method in his work is wrong and that his job is to find how a new method can be devised to replace his present one, and in so doing he is leading his field and he will therefore be successful.

There is a tremendous need at the present time for the development of engineering in connection with welding. Methods of forming, methods of welding, designs for the minimum cost, are wide open fields in which but a small amount of work has been done and then by very few companies.

In this field is the greatest opportunity for engineering talent that now exists—it would seem to me that this would be an inspiration particularly to the younger generation of engineers for in this is the opportunity which they have dreamed of from the first.

DISCUSSION

A. J. Standing*: The trip this afternoon both to the Cleveland Crane & Engineering Company and the Lincoln Electric Company, added materially to our store of welding knowledge.

Our welding in the steel plants has long been a tool of considerable value from the maintenance standpoint and is now coming into its own as a production tool. We in the steel plants have largely made use of it, however, as a repair tool. The Welding Committee, which we formed in the Association will correlate the various data which has been established by each electrical department in the steel industry into a tabulation so we can gain from the experience of others without the tedious process of going through the mistakes and failures which each one of us has had so far.

Mr. Lincoln had an editorial in the April issue of the Iron and Steel Engineer, in which he stressed the relation between the tonnage of castings and the possible tonnage of structural material which would replace those castings were it possible to be converted entirely to welding. I think one of our jobs is to sell this idea to our companies and at the same time sell that additional tonnage of structural steel.

One problem of welding as applied in the steel plant is the proper application of various types of welding. We have heard today primarily of electric welding, whereas in our work in the plant we come in contact with the gas welding in its various forms and electric welding with both carbon and metallic electrodes. Some of us think each type has its own specific field where it is more efficient than in the other types. That is largely a matter of opinion.

One thing we all have to do is to overcome a certain amount of prejudice which now exists against welding, prejudice in the minds of the men in our various plants who have been loath to see things done the new way. In order to overcome this, our procedure in welding must be careful and cautious, and we must make every effort in order to be successful, because the smallest chance of failure will be greatly multiplied. There is also a tendency to forget that failures have occurred in riveted, cast and other types of structure.

In connection with welding, we must not only be able to predict the result with a reasonable degree of certainty, but we must obtain those results. That involves welding equipment of high character, but it also involves primarily welders, because in spite of all the equipment, we still appreciate the fact that today about 85 per cent of a good weld is up to the welder.

That means that in the steel plant or in any plant of maintenance or production work, we must train and develop welders so we will have men who can consistently repeat given results.

*Elec. Supt., Bethlehem Steel Company, Bethlehem, Pa.

There are two ways of getting welders. One is to take a cast-off welder from somebody else, with all his faults and failures, for which he was probably fired some place else. The other method is to develop your own welders. I think the latter procedure will be found to be more satisfactory, particularly if we are fortunate enough to have some man in our organization who is capable of overseeing and instructing the proper application of welding.

That brings up another point upon which I want to touch, so the various points will be brought out in further discussion. That is the fact that welding has to a certain extent entered our colleges and should enter to a much larger extent. The technical graduates today should be familiar with welding before they meet it in the field. They should have an opportunity in college to analyze the processes of welding so when they come into the industry they will be in a position to step in and understand welding in its application and design.

It was my privilege recently to attend a welding symposium in one of the eastern universities, to which the various manufacturers contributed their share, both in equipment and demonstrations, so the students who attended that day's session had a very good panoramic view of welding and its possibilities. Those boys will, therefore, go out with some idea of what a welded job looks like, rather than meeting it absolutely uninitiated when they get out to actual practice.

Another feature which I think is important is the fact that the engineers who design structures will, as Mr. Lincoln put it, have to think in terms of welding. The tendency, of course, will be to take the old design and weld it. That may or may not be the best procedure. It may be that a new design will have to be conceived which will adapt itself primarily to welding.

I think that is particularly true in connection with the structural field.

There is one other big feature in structural welding, however, that is gradually being overcome. That is the building codes of the various cities in which the city engineers will have to be sold on the safeness and reliability of welding of structural steel buildings before we can expect that these methods will be adopted in the codes of the various cities.

I think there is unquestionably a great deal of welding talent in this room, and it would be very interesting to hear the discussion which will come up on these various points.

E. L. Upp*: Mr. Chairman and Gentlemen: I have nothing in particular to add to the discussion, except that we are very keenly interested in electric welding at our plant, and I am devoting quite a part of my personal time lately to learning all I can about it. I very much appreciate the opportunity of being here tonight and feel that I have gained considerably.

The electric welding of tubes at the present time seems to be making quite an advance, but will require some little time for consideration as to whether it is good or bad practice. We have not gone far enough to know, as yet.

*Elec. Engr., National Tube Co., Gary, Ind.

W. G. Wehr*: Mr. Chairman, you have all seen our welding out there. I think that is the biggest part of the story we have to tell.

But there is one suggestion here. It has been said that about 85 per cent is up to the personal man. I think that is true in lots of other crafts, but we don't recognize it as such. It is true that if you get into welding you have trained welder, as you have a trained machinist, a trained roller or a trained electrician. It is a new art to us. We are not familiar with it. We think it is greater than any of the other crafts.

I think if you go into it as deeply as we have, you will find that it isn't any more difficult to obtain an individual skilled in that art, to produce satisfactory welding than it is to operate any machine or operate a rolling mill or any other equipment.

That is all I have to say.

J. C. Cumberland†: I should at least have had a little warning here because this is very much of a surprise. I hope you didn't intend for me to answer those questions you raised in your statement just now. You have certainly opened a wide field in the welding of steel and the diameter of rods, and so on.

There is one thought though that I have which is more or less along the line of what the representative of the Cleveland Crane & Engineering Company mentioned. That is the personal element in welding; the human equation.

You have heard so much about it recently and all the stress seems to be laid upon the poor welder. You harp upon the idea that he must be a hundred per cent man, that he must be first-rate in every respect.

I don't believe you can draw a single parallel to that in any other line of work, except possibly the artist. The human element, in my mind, lies entirely with you men here tonight, you men who are in the executive positions and in the advisory positions, to make sure that the operator has the proper equipment to work with, the proper material to work with, and supervision to see that he does it in the correct manner and in the most up-to-date and most recently-developed methods.

Other than that, I don't think I have anything to add to the discussion.

S. L. Henderson‡: I do not believe I can add anything of value to what has already been said. I have the pleasure of being with the gathering this afternoon and I was very much interested in the several large welded pieces I saw, and from all appearances they looked perfect. I think we have just scratched the surface of welding but it is rapidly coming to the front, and without doubt has become an important factor in plant maintenance. We find it possible to weld a particular piece or plate in place thus saving considerable labor and time in making repairs.

Grover Hughes§: Mr. Chairman, to increase the confidence in welding, I might say that at the beginning of the World War, the Russian Government made a request for bids on hospitals that might be of a portable nature. The specifications were very rigid.

In December of 1914, the Truscon Steel Company designed and in 1915 delivered to the Russian Government the first 100 per cent all-welded all-steel buildings that were ever put on the market. That was the beginning of our standard steel buildings that have been developed and that have stood the test of over 13 years.

At the beginning those buildings were welded entirely by the resistance method of welding which was spot welding and butt welding. Since that time larger structures were required and arc welding has taken the place to a large extent. However the roof trusses are still being spot welded instead of using rivets as was the first design in 1915.

In 1919 a crane runway was installed in a building that was erected in 1912. The brackets were arc welded to columns and mill length I beams use for crane girders. The I beams were arc welded to the brackets and splices of these beams were arc welded much to the manner of fish plates on railroad rails. The rails were laid on the I beams and welded with a four inch bead every thirty inches, on each side of rail.

In 1924 this runway was increased from 618 feet to 1,400 feet and is in perfect condition after a period of nine years. Showing arc welding if properly done will stand the severe tests of crane service.

This runway has three three-ton, forty foot span cranes, 450 feet per minute bridge travel, 50 foot hoisting speed per minute and trolley speed of 200 feet per minute full load. Of course larger cranes would require larger structural members but this runway has stood the tests of time and is in perfect condition.

E. H. Martindale*: I don't know anything about welding. As Will Rogers says, "All I know is what I read in the paper."

I would like to ask Mr. Lincoln the relative merits of D.C. and A.C. welding, both as to operation and quality of finished welds.

J. Lincoln: I think that those who have had experience with both classes and both methods of welding will grant that the D.C. machine produces on the average a better weld.

One reason for that is this: As you know, when an arc is drawn, more heat is developed at one electrode than at the other. In the case of a carbon arc, the positive terminal is very much hotter than the negative terminal. In the case of the metallic arc, the same thing is true to a less extent. So I imagine the heat at the positive crater in the metallic arc would be represented by 60, while the heat at the negative crater would be represented by about 40.

It is quite evident that you want your heat on the work because the work has a very much larger cross section than the electrode. By having direct current you can get your heat to a greater extent on the work than you can with the alternating current where the heat from the nature of the case must be equally distributed between the two terminals.

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†Welding Engr., General Electric Co., Philadelphia, Pa.

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§Truscon Steel Company.

*Gen. Mgr., Martindale Electric Co., Cleveland, O.

Grover Hughes: Mr. Chairman, we have about 80 arc welders in the plant, of which about 29 are D.C. and the remainder are A.C. The A.C. is a little speedier, and from actual tests as far as appearance and strength of weldings is concerned, I don't see any difference.

But the power company raises a great question. Inasmuch as the A.C. welder has a very poor power factor, it is necessary that you add a static condenser at the welder, so the cost of the two machines, when you get them together, is about equal, as far as our experience has been, and I would say that the service on one is as good as the service on the other as far as our work with the A.C. is concerned. It is a little speedier but you are running into some trouble with the power company, owing to the fact the power factor of the A.C. welder is low and a static condenser is needed for the correction.

J. C. Cumberland: I would like to ask Mr. Hughes how he can explain that the A.C. is speedier since the positive side of the arc is twice as hot as the negative side in direct current.

Grover Hughes: That is a very simple proposition. The only thing you have to do is find out the KWH input in your A.C. and D.C. welding machines then measure the lineal inches of deposited metal on each machine, then by comparing results you arrive at the answer to your question. This is the way we did it in Youngstown. Try it.

In regard to this theory about the positive side of the arc being twice as hot as the negative side, I would have to see more positive proof before I banked on that very heavily. As the literature of your company estimates the arc temperature. But the actual number of inches that a man will lay down with a given KWH energy consumption with the A.C. welders in our plant is greater than the number of inches he will lay down on the D.C. welders. That is the way I find that the A.C. welder is speedier than the D.C. Welder.

E. W. Henderson*: It happened that a few days ago I had the honor, or the duty, of preparing a committee report for one of the national societies, and in getting together data for that report I was surprised at the large amount of welding which has been done in the last year. It is remarkable in the diverse applications and number of applications. All electrical machine manufacturers are using it more and more each year.

I am present at your meeting as a guest, and if my associate guests will permit me, I would like to express our thanks to the Association of Iron & Steel Electrical Engineers for a very enjoyable and profitable evening.

J. S. Lincoln: We have heard with a great deal of interest the remarks of Mr. Hughes on A.C. welding. If Mr. Hughes is correct in his statement then a very serious injustice has been done to the Steel Industry in selling them D.C. equipment. Not only this, but all manufacturers of D.C. welding equipment and all purchasers of this type of equipment have made a similar mistake.

However, in view of the fact that probably 90 per cent of all welding in use today and of all welders being manufactured today are D.C., we feel sure that Mr. Hughes must be in error in his deduction, and I am inclined to believe that Mr. Hughes is just a little over enthusiastic as I have understood that he is the designer and builder of the A.C. machines which he has in use in his plant and naturally a father is prouder of his own son than anyone else can be.

I have also understood that Mr. Hughes company have later purchased some D.C. equipment in preference to A.C.

I think that I am perfectly safe in saying if you would ask 1,000 operators who had had experience with both A.C. and D.C. welding that 95 per cent of them would tell you they could do faster work, better work and certainly much neater work so far as appearance is concerned with D.C.

In this connection it may be of interest to state that several years ago we purchased some top boxes for our own plant. The appearance of the welding was very severely criticized by our Manufacturing Department and our Purchasing Department in taking this up with the representative of the Hughes' company received the answer that this work should not have been done with A.C. welding equipment and as every one knew you could not do the same quality of work on this as you could with D.C.

A. G. Place*: Is there any further discussion? If not, I think we will all join in thanking Mr. Lincoln and the members of the Cleveland Section for this day and evening on welding. Welding seems to be growing so rapidly and making so much progress that facts that are only thirty days or sixty days old, sometimes are already obsolete. It is hard to keep up with the procession on welding right now, the way it is sweeping all over the country, and it looks as if it were going to increase very rapidly.

One of the things the Association wants to do is to correlate the facts on welding. I think we have made a good start tonight, and I think next time we will have more facts to present.

*Reliance Electric & Engineering Co., Cleveland, O.

MARTIN J. CONWAY

M. J. Conway, Combustion Engineer, Lukens Steel Company, Coatesville, Pa., and Chairman of the Combustion Engineering Division of the A. I. & S. E. E., who has just returned from an extended trip through the various countries of Europe.

Symposium High Tension Insulators

The following symposium covering High Tension Insulators was prepared by the leading insulator manufacturers of the United States with a view of assisting the Iron and Steel Industry in all future installations of this character.

With the increasing use of High voltages in the steel industry and the closer form of co-operation between the central stations and the power plants of the Iron and Steel Industry, the Association of Iron and Steel Electrical Engineers are anxious to obtain for their transactions, data and information concerning the distribution of electrical energy, especially at the higher potentials.

A close analysis of these papers will reveal many interesting features and is worthy of continued reference and use.

The titles of the papers along with the names of the authors are presented herewith:

"Hardware and Insulators," by D. C. Hopper, Supt. Overhead Lines Division, Duquesne Light Company, Pittsburgh, Pa.

"Transmission Hardware and Insulation Troubles," by A. N. Cartwright, General Supt. Power Division, West Penn Power Company, Pittsburgh, Pa.

"Transmission Line Insulation and Overhead Ground Wires," by W. W. Lewis, Engineering Dept., General Electric Company, Schenectady, New York.

"Mechanical Design Characteristics of Insulators," by G. M. Barrow, Mgr. Engr. Dept., Westinghouse Electric & Mfg. Company, Derry, Pa.

"Dirt on Insulators," by G. W. Lapp, Chief Engr., Lapp Insulator Company, Le Roy, New York.

"Protection from Flashovers," by H. B. Vincent, Manager, Field Engineering Service, The R. Thomas & Sons Company, East Liverpool, O.

"Protection of Transmission Lines," by D. H. Rowland, Research Engineer, Locke Insulator Company, Baltimore, Md.

Editor.

*Hardware and Insulators**

By D. C. HOPPER†

Summary

The following requirements and other factors affect the selection, design and use of hardware and insulators:

1. Complete and accurate information of the service conditions.
2. Uniform electrical and mechanical strength of the hardware and insulator.
3. Use only the necessary auxiliary protective equipment.
4. Select for slow ageing.
5. Make the conductor attachments as few as possible.
6. Avoid material which will radiate electric waves.
7. Standardize hardware so as to be interchangeable.
8. Small in size and light in weight as possible.
9. Simple, accurate and thorough tests when new and throughout service.

History and Importance of Hardware and Insulators

PRESENT day line hardware and porcelain are usually extremely high grade and compare very favorably with any other dependable product used in electrical work, realizing that no product made by man and machine is perfect. This cannot be said, however, of some of the hardware and insulators which were manufactured during the last twenty-five (25) years. In fact, there were times when electrical men believed that the porcelain insulator, especially the suspension type, would never be satisfactory. Research work in the ceramics of porcelain, improvements in hardware design and materials used, and analyzed facts produced by the operating engineer have all helped the manufacturers to assemble porcelain and metal into a complete insulator that ranks today as one of the most reliable parts of the electrical transmission system.

During the early period of insulator development, neither the electrical nor the mechanical requirements of insulators were very rigid because the voltage applied was low. Hence, there was no real need for a refined product to operate on low voltage lines, having short spans and small conductors. The increase in operating line voltage during the last twenty (20) years created the demand for larger and better insulators.

With the suspension insulator, developed about 1908, came lines of higher voltage; the pin type insulator having a limited application to transmission systems of 66 kv and below.

From 1913 to 1915 a great improvement was made in the development of insulators and hardware, as a result of the very serious failures in attempting to operate higher voltage transmission lines. The electrical, mechanical and ceramic engineers made an extensive study of the cause of these failures and the insulator manufacturers, through scientific analysis and experimenting, developed the manufacture of the ware and the assembly of the units to a more reliable product. Since then, very definite

*Presented before Pittsburgh District Section, A.I.&S.E.E., March 3, 1928.

†Supt. Overhead Lines Division, Duquesne Light Co., March 3, 1928.

and complete analyses have been made of insulator failures and a porcelain product has been developed which is very reliable.

The manufacturers, since 1920, knowing the fundamental characteristics of insulators and transmission lines, have given their attention more particularly to further refinement of the porcelain assembly, with the result that the product is of a very high grade, both electrically and mechanically. I thoroughly believe that the insulator will eventually be the most satisfactory unit of a transmission line.

In the design of an insulator, different parts can be made almost 100% perfect, but an assembly of the perfect units must by necessity, be a compromise; for instance: It is necessary to sacrifice some of the flashover values to gain strength or to decrease weight. Accepting these limitations and handicaps, I propose, in this paper, to outline the desired requirements fundamental to insulator design and associated hardware which will provide for the best operation of an electrical transmission system.

If an insulating material (the insulator and its hardware attachments) could be obtained with practically no weight, which occupies very little space, having all the mechanical strength needed, which is indestructible under arc, age or weather conditions and with infinite resistance, the operating engineer would have a grand and glorious feeling, the insulator manufacturer could get only new business, since there would be no breakage or replacements, and the customers or users of electricity would never have an outage or shutdown which is caused by poor insulation.

We have reached the present art of the industry through the process of elimination because there are so many things to influence the life, strength, and other properties of materials.

FACTORS AFFECTING THE DESIGN AND USE OF HARDWARE AND INSULATORS

1. Climatic and Service Conditions

The rapid growth of electrical systems and the increasing capacity supplying these systems have made it very difficult to anticipate future requirements over a longer period than a few years. As a first requirement for the specifications of any electrical system, it is necessary to design electrical equipment, not only to withstand the normal requirements, but with a sufficient factor of safety to withstand the varying moisture, wind, temperature and sleet conditions, together with impact and vibration stresses and dirt, smoke, acidic or other atmospheric conditions which may prevail. Knowing the topography of the country and the service expected of the electrical equipment, the design sometimes becomes a matter of compromise between the first cost of the equipment and the operating and service interruption expenses. Living conditions today are becoming more and more dependent upon a continuous supply of electrical energy, whether this be between the power plant and the various consumers of the central stations or between the power plant and the various mills of the steel and other industries. An interruption of service in any case will result, not only in a serious delay in plant or mill production and damage to material in process, but also will involve the cost of making repairs, all of which affect the economic and social conditions prevalent at the manufacturing plants and the employes, furthermore the public concerned, may develop a hostile attitude towards the company supplying the electrical service. With these things in mind the size of the conductors, spacing of the supports and the spacing between conductors is more or less a compromise influenced to a greater degree by a guess as to the future demands which may be placed upon the electrical lines, power and sub stations and transformers connected thereto.

2. Strength of Materials

All hardware, porcelain and other materials, whether separate units or an aggregation of units, should have a uniform strength, continuous throughout its life of usefulness or over a definite period of years. This strength should be equal in any position to that of the structures, conductors or other auxiliaries forming a part of the transmission system, even though subjected to the constant abuse of lightning, storms and extreme weather and temperature conditions previously mentioned. The electrical characteristics of insulators, such as puncture and flashover values are very important and should be of a larger value than the surrounding air, which after all is the limiting factor of the voltage which may be successfully applied.

3. Auxiliary Protective Equipment

To prolong the life and strength of conductors where attachments are made and to protect the insulation and hardware from the intense heat and power arcs, and to add dependability for continuous service, especially designed protective equipment, is often used, such as, lightning arresters, overhead ground or static wires, arcing horns, arcing rings or arcing shoes, insulator flux control, and graded insulators for voltage distribution. The purpose of the protective or auxiliary equipment is to improve service. The first cost and maintenance of protective equipment, the advisability of installing more and larger protective units, and the seriousness of service interruptions are complex and difficult problems; problems which can be solved only by close co-operation between the user of electricity and the company supplying the electrical service, where all the facts are fairly and accurately presented and honestly analyzed.

4. Deterioration and Ageing

The continuous attacks of the bitter wind, sleet, acids, smoke, temperature cycles and other ageing or weathering combined with the electrical and mechanical stresses and system capacity are the actual influences which determine the life and durability of the hardware and insulator. The mechanical and electrical strengths of the new material and the effect of deterioration over a period of years establish over-all dependable characteristics or life which may be expected. By cleaning and resurfacing, deterioation of materials can be lessened and the useful life prolonged, but this is an operating expense which, to a certain extent, can be economically reduced through the use of better materials, having a greater first cost.

The deterioration of the hardware and insulators should not shorten the over-all life of the line. The painting of hardware and the periodical testing of insulators are the operating methods of extending

the life of material and detecting bad insulators, which insulators can be replaced prior to failures or to service interruptions. Commercial test sets are on the market for making insulator tests on both pin type and suspension insulators. Soot, smoke, cement and other deposits on the insulators can sometimes be removed by cleaning, otherwise the remedy is a new insulator.

5. Frequency of Attachments

If electrical conductors could be suspended permanently in air without supports, the problem of insulation would be solved, but to date no one has perfected a gravity resistance device; therefore, points of support are necessary and experience shows that the fewer the number of attachments made to an electrical conductor, the less the number of failures. Realizing that there are definite limits to the strength of conductors and of supporting towers, it becomes a compromise as to the most satisfactory spacing of insulator attachments or supports. The tendency has been to use larger and stronger conductors, fewer and stronger towers, higher and higher voltages requiring insulators of greater mechanical strength and more dependable electrical characteristics, which, stated in the well known language of business means—more service and more power for less dollars, and more kilowatt hours per dollar of investment with a lesser number of service interruptions.

6. Radio Interference

In the past few years another development of the electrical art has added to our problem—radio communication. Space voice communicating systems are extremely sensitive to electrical energy dissipation and the radio receiving set will sometimes pick up most of the electric waves within the frequency range for which the set is designed. The greater the sensitiveness of the radio set, the more and louder the squeaks and squeals. The radio squeaks and squeals may come from very many sources and some do come from the transmission lines. Small pin points on conductors, insulators and ungrounded hardware, loose cotter pins, bolts and other hardware attachments may send out, under certain conditions, noises into the air or along a conductor, which will interfere with the reception by the public of radio broadcast programs. Also, excessive corona losses may seriously affect radio receiving sets which are located near a high voltage transmission line.

7. Assembly and Interchangeability

Hardware and insulators should be of a standard design to permit interchanging them on parts of the same or different electrical systems. The rapid expansion of the electrical systems (whether the systems of industrial plants or of the central stations) has made it very desirable to carry a minimum stock of insulators and hardware, which will fit anywhere on the systems and which can be replaced in a minimum amount of time, with the least expenditure of labor.

The seriousness of the lack of standardizing may be likened unto an auto with four different size wheels and tires. The chauffeur must carry four spare tires to protect him from a long delay in making repairs.

8. Size and Weight

It is advantageous to use materials which have the required strength and other requirements previously mentioned; that are lightest in weight and size, with sufficient ruggedness to prevent breakage when reasonably handled, in order to reduce transportation expense and insure convenience in handling and replacing without damage. All other things being equal, the material with the greatest salvage value is preferable.

9. Testing and Operating Records

Materials which may be easily tested electrically and mechanically are desirable. This principle also applies to ageing tests of material to insure the best design for the requirements. Simple and uniform methods of testing which are easily understood by the average person have decided advantages because it is difficult to compare test data made under different mechanical or electrical set-ups. It is equally important to keep operating and service records of insulators after they have been installed, and to cooperate with the manufacturer when any trouble or difficulties arise.

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*Transmission Hardware and Insulation Troubles**

By A. N. CARTWRIGHT†

THE Association of Iron and Steel Electrical Engineers has a manner of doing things and bringing together the best of talent that the field has to offer. It is not, within my memory, that any group or body had for its speakers the array of manufacturers' engineers of the calibre assembled by this Association and it is therefore with pleasure that I represent the West Penn Power Company in my capacity to assist in this program.

My function in this talk is to develop features of the insulation and hardware situation which have to do with troubles of the product or the application of the product of the various manufacturers here represented.

I think I have a fair understanding of the problems and I know I have a sympathy for the manufacturers in their attempt to overcome the problems with which they have to deal.

The very nature of the insulating medium is such that it requires a thorough knowledge and a never ceasing vigilance to produce a product with the degree of uniformity which they are now doing. The limits of tolerance are within such a narrow

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*Presented before Pittsburgh District Section, A.I.&S.E.E., March 3, 1928.

†General Supt., Power Division, West Penn Power Co., Pittsburgh, Pa.

band that very costly losses may result from a slight slip anywhere along the line of manufacture. The advance that porcelain manufacturers have made in their product is such that poor porcelain is a rare occurrence. It is, therefore, without any malice or any intentional breaking down of the confidence which certain products enjoy, that I am about to present the following.

Distortion of pin holes causes difficulty by not allowing the pin to seat properly. Insulator cocking over where the soft metal thread is used causes cold flow of metal, the whole structure assembly of pin and insulator being weak.

Insufficient droop of the top petticoat to allow clearance of the conductor when used on hillside or on long spans is sometimes responsible for the top petticoat breaking off and is always responsible for unnatural stresses in the insulator assembly.

Poor mechanical design of the tie groove either making a poor tie connection or possibly being weak and corner lip of the tie groove breaking off either in the process of making the tie or under severe strain conditions.

Radius of the tie groove is sometimes not sufficient to seat conductor in the bottom of the tie groove when used on angle positions. This causes a shearing off of the head or a portion of the head of the insulator.

Mechanical failures of the insulator due to assembly faults. These failures occur from insufficient allowance for expansion of the various assembly parts such as hardware, cement, and porcelain.

Mechanical failures due to inherent properties or design of insulating medium due to thermal changes.

Mechanical assembly suspension insulators to allow for buckling of string as in the case of broken conductor without damage to insulator shells. Lack of this feature is responsible for considerable breakage during erection.

Design of insulator and assembly in a manner that will render them radio interference proof. NOTE: Dissipated energy from even a loose cotter pin may cause radio interference several miles away.

The above are all features of mechanical design in various makes and designs of insulators at different times.

Damage by flash-over to insulators is responsible for many extended interruptions. An insulator that will continue to function even when wet at normal line voltage after flash-over has occurred has a very great value over the insulator which will require the line to remain out of service after flash-over has occurred. Flash-overs causing damage to the extent of dropping the line have occurred.

Dirt, acid or metallic fumes are responsible for high fatality of insulators in some districts. This particular feature has been given only limited attention in the design of insulator units, that is, to give sufficient operating values under these conditions or to lengthen cleaning or changing period to a reasonable degree. Surfaces of present insulators are such that considerable difficulty is encountered in cleaning of the units. Normal design of insulators is such that it acts as a precipitator causing dirt and various foreign objects in the atmosphere to be thrown into normally protected area and deposited on the surface in such manner as to render absolute cleaning almost impossible.

Wooden pins have certain advantages over steel pins. These advantages are more or less offset by pin digestion or pin burning. Certain insulators have better features from one or the other of these standpoints but few have both features.

On devices for protection of suspension strings from flash-over, we will no doubt hear considerable today.

West Penn's experience is such that we do know that the ordinary type of arcing horn that is offered by practically all of the manufacturers is not the remedy for rendering insulators immune to damage by flash-over.

Leaving the line type of insulation and thinking of bushings for switches and transformers which are very frequently operated as a unit with the line, we probably have a higher unit failure than any other type of insulation. This high percentage of failure occurs even with increased vigilance because it is a recognized weakness. The type of insulation which calls for this insulation measurement on a monthly basis is far from being ideal. Even with a program such as this the bushings which last Saturday might have meggered infinity, might today megger 30 megohms.

From the hardware standpoint the protective coating is and will be responsible for the greatest loss of money and, although not leading directly to line failures, it still requires line outages for replacement after hardware has deteriorated to a point where it is deemed unsafe to remain in service. Just ordinarily good galvanizing is not good for ten years' service in the best of atmospheric conditions surrounding the industrial center of Pittsburgh. If additional life beyond that of protective coating is considered, attention must be given to the materials which go to make up the hardware from the corrosion standpoint.

The effect of the hardware on conductor must be considered only when used in connection with suspension type of construction. Roughness in the clamps will cause serious injuries and abrasions. The electrolysis between conductor and hardware is also a serious item, especially in the presence of a polluted atmosphere. The sudden dampening of vibration is responsible for a number of failures and very considerable money expenditures and line outages occurring while correcting this condition.

This makes a rather formidable array of troubles, many of which can be laid at the door of the insulator and hardware manufacturer, but also many can be laid at the door of the design engineer himself.

There is information available at the present time to materially assist the design engineer in his own specific problem if he will but take advantage of this engineering information. The insulator manufacturers have collected a valuable fund of data from operating experience and laboratory tests. While some of this data is contradictory in some points with different manufacturers it is still possible, with the particular objective to be obtained and fair knowledge of all factors entering into the problem, for the engineer to be very materially assisted in making selection of devices for his particular use.

Transmission Line Insulation and Overhead Ground Wires *

By W. W. LEWIS†

DURING the past few years the great majority of overhead transmission systems in this country have grounded the neutral, either solidly or through a moderate resistance. Overvoltages due to arcing grounds on such systems are practically absent. Overvoltages due to switching are in general no longer feared on systems with modern insulation and apparatus.

Lightning is the only cause of high voltage which gives serious concern at the present time. In order to combat lightning, transmission engineers have been adding more and more insulation to the lines as well as various special arcing devices, overhead ground wires, etc. A great deal of work has been done in studying lightning and its accompanying phenomena by means of the klydonograph and surge voltage recorder.

Laboratory work has thrown a great deal of light on the effect of impulses on insulation, both of apparatus and transmission lines.

The question now arises as to whether we can, in the light of present knowledge, design a transmission line and its connected apparatus so that they will be reasonably safe against breakdown and interference to service due to lightning. Let us first examine the data upon which such a design shall be based.

Sixty cycle flashover tests on insulators have been made on strings of various numbers of discs. Most of these tests have been made on standard 10-inch discs spaced 5¾ inches apart. It has been found that the flashover value when plotted against length of string in inches, gives a straight line on log-log paper. The length of string is the spacing per disc times the number of discs. The curve may also be used for insulators of other spacings not differing greatly in proportions from the 10-inch disc spaced 5¾ inches apart. In this case it is only necessary to multiply the spacing per disc by the number of discs, and enter the curve with the total distance. Table I gives the length of string and 60 cycle flashover for strings of 10-inch discs spaced 5¾ inches apart. The flashover values are plotted against number of discs on Fig. 1.

The impulse flashover of such insulator strings assumes various values, depending on the nature of the impulse, the steepness of its front, the slope and length of its tail, etc. Numerous tests have been made with the standard wave of the High Voltage Laboratory at Pittsfield on insulator strings of various lengths, and these tests have been repeated with a great deal of consistency.

The Pittsfield wave is a single impulse with a very steep front, rising to its crest value in approximately one-quarter microsecond or less, (depending on the load on the test set), and then decreasing to 50 per cent of the crest value in approximately five microseconds, i.e. the portion of the wave above 50 per cent crest value is approximately one mile in length. This wave is represented on Fig. 1.

The manner of making the tests is to impress on the insulator string such voltage that the arc-over takes place somewhere on the tail of the wave. The actual flashover value is determined by adjusting a sphere gap in multiple with the insulator string until about one-half of the flashovers take place over the insulator string and one-half over the sphere gap. The setting of the sphere gap is then taken as a measure of the flashover potential. The values thus determined (Table I), plotted against length of string, again form a straight line on log-log paper somewhat above the 60 cycle values (Fig. 1.)

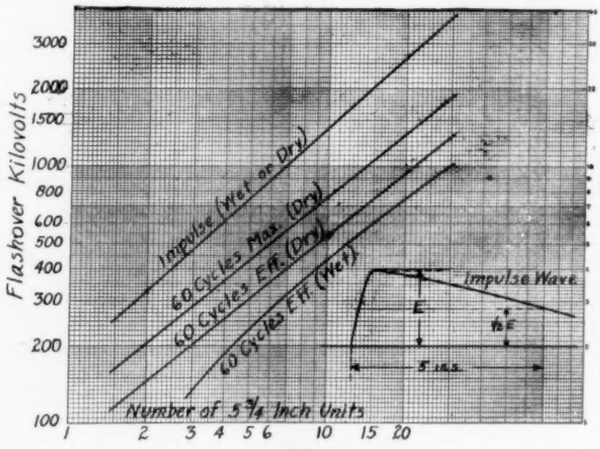

FIG. 1

The ratio of the impulse flashover to the 60 cycle maximum or crest flashover is called the impulse ratio. It will be seen that this varies from approximately 1.5 to 2 within the range of the curves. A fair average would be 1.8.

TABLE I

Flashover of Insulator Strings
Based on 10-Inch Discs Spaced 5¾ Inches

No. Discs	Length of String Inches	60 Cycle Arc-over Kv. Eff.	Impulse Arc-over Kv. Max.
3	17.3	200	470
4	23.	250	610
5	28.7	300	750
6	34.5	360	890
7	40.2	400	1020
8	46.	450	1150
9	51.7	500	1280
10	57.5	550	1410
11	63.2	600	1520
12	69.	650	1660
13	74.7	700	1780
14	80.5	750	1900
15	86.3	800	2020
16	92.	850	2140
17	97.7	900	2260
18	103.5	950	2380

*Presented before Pittsburgh District Section, A.I.&S.E.E., March 3, 1928.

†Engr. Dept., General Electric Co., Schenectady, N. Y.

If an extremely high potential is applied as compared with the flashover value of the insulators on the tail of the wave, then flashover will take place on the front of the wave. For the particular wave we have been discussing, it has been found that the flashover values thus found are very consistently about 20 per cent greater than the values determined when the flashover takes place on the tail of the wave. For other waves, of course, there may be a somewhat different relation between flashover on the front and tail of the wave.

In actual practice flashover of insulator strings may take place either on the front of the wave or on the tail of the wave, and sometimes even on the

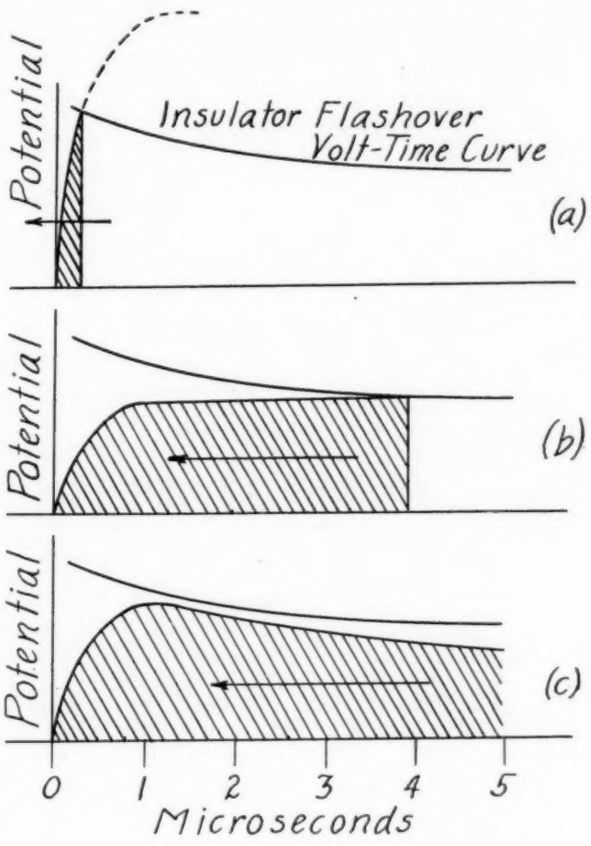

Fig. 2

crest of the wave. In case flashover takes place on the front of the wave, then only a small portion of the wave passes on to the rest of the line and station apparatus (Fig. 2-A). When flashover takes place on the tail of the wave then a longer portion of the wave passes on and as this represents a greater amount of energy, the wave is capable of doing considerable damage if it reaches station apparatus. (Fig. 2-B). If the value of the wave is not quite sufficient to flash over the insulator string either on the front or the tail, then the full wave will pass on toward the station. (Fig. 2-C). In each case there may be considerable attenuation along the line before the wave reaches the station.

Some data have been taken on oil-filled bushings and pedestal type insulators, such as used on disconnecting switches. These data indicate an impulse ratio slightly higher than for line insulators. There appears to be a similar difference of approximately 20 per cent between the flashover value on the tail of the wave and on the front of the wave with the particular wave used in the tests.

During the past few years considerable data has been accumulated by means of the klydonograph and surge voltage recorder, which has indicated the maximum voltage to be expected on transmission lines with present standards of insulation to be in the neighborhood of 10 to 12 times the crest value of the line to neutral voltage of the system.

TABLE II

Insulation of Actual Lines

System Voltage KV	Crest Value Line to Neut. Voltage KV	No. of Insulator Discs. Range	Weighted Average	Impulse Flashover KV	Ratio Impulse to Normal Voltage
66	54	4-6	5	750	13.9
88	72	5-7	6	890	12.4
110	90	6-9	7	1020	11.3
132	108	9-12	10	1410	13.1
154	126	10-12	10	1410	11.2
187	153	10-12	10	1410	9.2
220	180	12-16	13	1780	9.9

Table II gives the average number of insulator discs used on actual systems, also the minimum and maximum number of discs for the various standard system voltages. The impulse flashover value is also given. From this table it will be noted that the impulse flashover value is in the neighborhood of 10 to 14 times the crest value of the normal line to neutral voltage. This, together with the results of the klydonograph study, would indicate that the impulse flashover values given in Fig. 1 are fair values to use for the type of impulse which causes flashover on actual systems.

According to Mr. F. W. Peek's investigations, we may take the maximum potential gradient which may be induced on a transmission line by lightning as approximately 100 kv. per foot of height of conductor. Actually, there has been measured by surge voltages recorder, potentials which indicate gradients as high as 40 kv. foot of height. The readings obtained are subject to the fact that there is no assurance that the surge voltage recorders were located at the point of highest potential. The potentials are naturally limited by the insulator flashover, and such flashover potentials would require gradients in some cases as high as 60 kv. per foot of height.

Assuming that the maximum potential gradient of 100 kv. per foot of height can be obtained and assuming further that the flashover values given in Fig. 1 are substantially correct, then we have a means of determining whether or not a particular line will be subjected to flashover.

Mr. Peek in his laboratory investigations has determined fairly well the effectiveness of overhead ground wires. The protection afforded by the overhead ground wire depends on the distance of the ground wire from the conductors, on the height of the conductors above ground, and on the size of the ground wire and conductors. Generally speaking, however, any one of these factors may be varied within the range of practice without affecting the protective ratio to any great extent. The resistance

of the connection to ground also has considerable influence on the protection.

The protection afforded by ground wires, based on calculation and laboratory models, has been found to be approximately as follows:

With one ground wire the induced voltage is reduced to about 50 per cent of the value without ground wire, with two ground wires to 35 to 40 per cent, and with three ground wires to 30 to 35 per cent. The best average protection is given for the arrangement in which the conductors are horizontally placed.

In placing ground wires it is desirable to adhere to the following general rules:

1. The wires should be connected to each tower or connected to ground at each wooden pole.
2. The resistance of the tower footing or the pole ground must be low in order to give the maximum protection.
3. The ground wire should preferably be of the same material as the conductor, or other high conductivity material. This will prevent rusting and will have an appreciable effect in reducing the impedance of the system to line-to-ground short circuits. It will also reduce telephone interference by shunting a good portion of the short circuit current away from the ground.
4. The ground wires should terminate at the station structure rather than at the first or second tower out on the line. This assures that the last span or two near the station will be protected and that there will be no abrupt change in the surge impedance of the line at the terminal of the ground wire. Such a change in surge impedance tends to cause an upward reflection in the voltage of a wave arriving on the transmission line.

The conductivity of the ground wire apparently has very little effect on its protective value, as the protective value depends on the reduction in charge on the line conductors and the increase in capacitance of the conductors to ground, and this is independent of the material of the ground wire. High conductivity is very beneficial, however, in relaying and in preventing telephone interference as previously mentioned.

Now, if we know the potential gradients which may be obtained due to lightning, the flashover value of the line insulators and the protection afforded by overhead ground wires, we are in a good position to determine what must be done to render the transmission line fairly safe from insulator flashover.

In Table III are given the actual average heights of the lowest conductor at the tower for the various standard system voltages as disclosed mainly from a study of the data given in the Electrical World Supplement of January 3, 1925. In this table are also given the potentials which may be obtained with a gradient of 100 kv. per foot. Comparing these potentials with the flashover value of the line insulators in Table II, we see that it is possible to have insulator flashover under the assumed conditions for every system voltage.

Assuming the average heights shown in Table III and a horizontal arrangement of conductors with two overhead ground wires placed above and between the conductors, the potential induced on the conductors will be reduced approximately to the values shown in the fourth column of Table III. Now, in order to prevent flashover, it will be necessary to use the number of insulator discs shown in the fifth column of the table. The insulation required to produce immunity in this manner is considerably higher than the present standard.

TABLE III

Height of Actual Lines and Insulation Required to Prevent Flashover

System Voltage	Average Height of Lowest Conductor at Tower Feet	Possible Lightning Potential 100 Kv. per Foot	Potential with Two Ground Wires Conductors Horizontally Arranged	No. of Ins. Discs Required to Prevent Flashover	Flashover of Insulator Discs Kv.
66	35	3500	1290	9	1280
88	39	3900	1440	10	1410
110	47	4700	1740	13	1780
132	47	4700	1740	13	1780
154	50	5000	1850	14	1900
187	50	5000	1850	14	1900
220	56	5600	2070	16	2140

Of course, if the conductors were arranged vertically, the situation would be still less favorable. For example: Let us assume the heights for top, middle and bottom conductor shown in Table IV. Then the potentials without ground wire at 100 kv per foot of height would be as given in the third column of the table. Now assume that there are two ground wires placed vertically above the two circuits of a double circuit arrangement. Using the protective ratio previously mentioned, we would arrive at the potentials given in the fourth column of Table IV. In order to prevent flashover in this case it would be necessary to use the number of insulator discs shown in the fifth column of this table.

TABLE IV

Vertical Arrangement of Conductors
Potential Induced and Insulation Necessary to Prevent Flashover

Conductor	Conductor Height Ft.	Potential Without Ground Wires 100 Kv. per Ft.	Potential With Two Ground Wires 100 Kv. per Ft.	No. of Insulator Discs Required to Prevent Flashover	Impulse Flashover Kv.
Top	75	7500	2480	19	2500
Middle	60	6000	2340	18	2380
Bottom	45	4500	2160	16	2140

It has been found by Mr. Peek that grading rings properly proportioned and properly located will increase the flashover value of a string of insulators, especially strings containing ten discs and over, approximately 10 to 15 per cent, and this effect may be taken advantage of in reducing the number of insulator discs or in increased factor of safety.

It is apparent from this study that the potential induced on a transmission line is independent of the operating voltage, except in so far as the height of the conductors and the number of insulator discs are affected by the operating voltage. In selecting the number of insulator discs, it may not be necessary to consider the extreme potential gradient of 100 kv. per foot of height. A gradient of 75 kv. per

foot will probably be sufficient to cover the great majority of cases, and a line insulated for this gradient would no doubt be immune from flashover except in rare instances.

Now what is the situation as regards apparatus insulation, especially transformer insulation. The insulation of power transformers is designed to withstand a certain 60 cycle high potential test, this high potential test being, for fully insulated transformers, two times the line-to-line voltage. The test is applied from high tension winding to low tension winding and ground. In the so-called reduced insulation transformers, which are built for operation with solidly and permanently grounded neutral, an induced voltage test of 2.73 times the leg voltage is given to the transformer windings.

Naturally the designers build into the transformer a factor of safety over the Institute test. Such a factor of safety has been worked out by experience and has proved ample to meet the various switching and arcing ground surges to which transformers are subjected.

With the range of line insulation shown in Table II it has been possible for transformers to be subjected to lightning voltages from 10 to 14 times the normal operating voltage with the average line insulation and more than that with the maximum insulation shown in the table. Such voltages of course, are subjected to the modification caused by lightning arresters, the capacitance to ground of steel work used in supporting bus structures, etc. Also on any system probably only a fraction of the lightning discharges take place near stations. However, it is reasonable to suppose that transformers have been subjected many times to ten times normal voltage. Transformers have operated under these conditions with remarkable success, the failures due to all causes including lightning, being only a fraction of one per cent per year.

It is reasonable to conclude that fully insulated transformers with present standards of insulation will operate successfully on systems with present average insulation. If such line insulation is increased, as now seems to be the tendency, then the transformer insulation must be correspondingly increased, unless the present standard line insulation is retained for a reasonable distance adjacent to the station, say, one-half to one mile.

If fully insulated transformers are on a par or slightly stronger than the present average line insulation, then it is apparent that reduced insulation transformers are too weak, as their strength is only about 80 per cent of that of fully insulated transformers. Reduced insulation transformers for this reason have no place on systems subjected to much lightning, unless the adjacent line insulation is correspondingly reduced.

In order to protect transformers now in operation and future transformers with standard insulation, it is recommended that the line insulation adjacent to stations be not increased beyond the values given in Table V for at least one-half mile from the station. Beyond that point there is no objection to increasing the line insulation to any value required to give good operation. Such a practice on the part of the operating companies will give the manufacturers a definite standard with which to compare their apparatus design.

If, for any reason, it is desired to increase the line insulation adjacent to the station, then the apparatus insulation should be increased correspondingly.

In cases where it is thought desirable to increase the line insulation and it is feared that maintaining normal insulation near the station will increase the number of flashovers, this may be compensated for by placing additional ground wires over this portion of the line thereby reducing the potential induced by adjacent cloud discharges to correspond to the reduced number of insulator discs. Such ground wires should extend to the stations and in some cases over the stations, in order to insure that the station apparatus secure the full benefit of the ground wires.

TABLE V

Recommended Line Insulation

System Voltage Kv.	Recommended 60 Cycle Arc-Over of Line Insulators-Kv. Effective	Corresponding Number of 10-Inch Discs Spaced 5¾ Inches
66	250	4
88	360	6
110	400	7
132	450	8
154	550	10
187	650	12
220	750	14

The impulse flashover value of standard General Electric bushings, is in general, on a par with the line insulation strength. If a wave gets by the line insulation without flashing over and reflects to a higher magnitude on reaching the transformer winding, then the bushing may flash over and thus offer a means of relieving the transformer insulation. The character and type of waves are so varied that neither the line insulation nor the bushing may be depended upon to protect the transformer in all cases. All that can be said is that if their flashover value is not too high with respect to the transformer strength, there is a pretty good chance that they will flash over and relieve the transformer of at least the greater part of the energy of the wave.

Sometimes power companies call for an especially tall bushing, where the transformer is operated in a district subject to smoke, dust, salt spray, etc. These foreign materials, together with moisture, reduce the flashover voltage of the bushing. In these cases the long bushing may be used to improve the creepage situation, and the impulse flashover may be kept down to correspond with the transformer insulation by a suitable auxiliary ring or horn gap. Such increased length bushings may afford only temporary relief from creepage as in time dirt will accumulate and their flashover voltage may be reduced to a value comparable to that of a standard bushing. Frequent cleaning may be necessary in either case.

In order to provide a further assurance of successful operation and take care of surges of all kinds, it is necessary to by-pass the incoming surge. The cheapest and most effective present form of such a by-pass, is a lightning arrester. Such an arrester if placed directly at the transformer terminals or as near to the transformer terminals as physically possible, will prevent appreciable reflection and hold

down the voltage to a value that is safe under all conditions.

To summarize: We have shown that it is possible to increase the safety of transmission lines and apparatus from lightning disturbances by adhering to the following principles:

(a) Construct the transmission line so that the conductors are as near to the ground as the necessary clearances will permit, and preferably build the line with the conductors horizontally arranged.

(b) Install one or two overhead ground wires in accordance with the design of the tower and the requirements for reduction in potential imposed by the height of the conductors.

(c) Use sufficient insulation on the line to prevent flashover with the maximum potential gradient that may be obtained with the number of ground wires used.

(d) Maintain recommended insulation (Table V) for one-half a mile or so from the station in order to protect station apparatus. Over this section additional ground wires extending to the station may be used in order to place this section on a par with the over insulated section as far as flashovers are concerned.

(e) Install lightning arresters immediately adjacent to the transformers so as to prevent reflection and hold down the potential to a comparatively low value.

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*Mechanical Design Characteristics**

By G. M. BARROW†

PORCELAIN is the material almost universally used for power line insulators. It is also used where the utmost reliability is desired in all line insulation, either power or communication.

Electrical porcelain combines the electrical, mechanical, thermal and chemical properties of a dielectric in such manner that properly treated in application, it furnishes an unsurpassed insulating medium. Although some of the physical characteristics are not what may be termed ideal, it is more adaptable for insulating purposes, than any other material. Electrically, it has high resistivity and rupture strength, small losses, and low dielectric constant and power factor. Mechanically, it has great compressive, tensile and shearing strength, is non-porous and non-hydroscopic; and though coming under the classification of a fragile material, possesses a degree of toughness that brittleness is avoided. It is inorganic, acid proof, and chemically more stable than any other ceramic material; and retains its insulating resistance over a greater temperature range. It lends itself to plastic forming in an early stage of manufacturing process, thereby giving a homogeneous material, free from internal stresses that occur in the molten type. Estimates place the number of porcelain insulators in use on power lines in the United States at approximately one half billion. Considering the number of points of insulation represented by this quantity, their service record is remarkable.

The use of porcelain for insulation is based fundamentally upon its electrical characteristics. However, the mechanical features of the manner in which it is applied in the completed design are of more importance to its successful operation. Some of the mechanics of electrical porcelain are listed:

Compression	52,000 Lbs. per Sq. In.
Modus of Rupture	10,000 Lbs. per Sq. In.
Coefficient of Expansion	5.4x106 per degree C.

1. Spark Plug Porcelain.
2. Wet Process Electrical Porcelain.

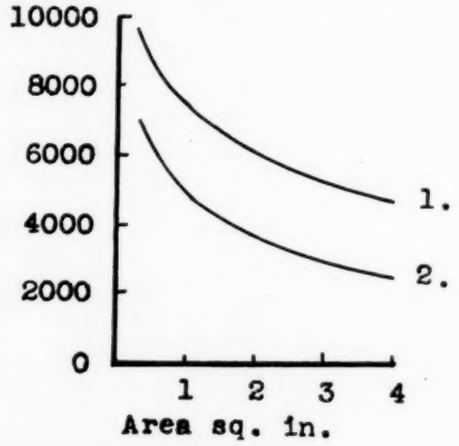
*Presented before Pittsburgh District Section, A.I.&S.E.E., March 3, 1928.

†Mgr. Engr. Dept., Westinghouse Electric & Mfg. Co., Derry Works, Derry, Pa.

The curve shows the relation of tensile strength to cross sectional area of test specimen and a comparison between electrical porcelain for insulators and that used for spark plugs. A value of 3,000 pounds per square inch is the average accepted for design purposes. The strength in compression is more than ten times that in tension and a better idea may be formed of its mechanics by a comparison with steel, as in the table:

	Compression	Tension	Modulus of Rupture
Steel	60,000 Lbs. per sq. in.	60,000 Lbs. per sq. in.	60,000
Porcelain	50,000 Lbs. per sq. in.	3,000 Lbs. per sq. in.	10,000

The function of a line insulator is to provide the mechanical support and electrical insulation for the conductor. On this basis, the insulator design assumes a balance between these two factors.



Curve 1.

The electrical factor depends upon the insulating quality of the material and the design characteristics, of adaptation to the electro-static field form, arcing distances and creepage surface. The provision of electrical porcelain of good insulating quality is a matter of the proper selection, and proportioning of

raw materials, and the correct and uniform methods of ceramic manufacture. The inherent principles governing field form and arcing distances control their application. The other factor takes into account the mechanical properties of the porcelain, enumerated above, and the manufacturing limitations; so that the final design is a combination of mechanical and electrical characteristics, and economical manufacturing cost, to meet a given application.

Line insulators can be divided into three general classes, on the basis of their design, namely—one piece pin type, multipart pin type and cap and pin suspension type.

The one piece pin type is used on the lower voltages and under favorable transmission conditions of, dirt accumulation and climate, as high as 15 kv. to 17 kv. As the name implies, it is fabricated in a unit mass; the mechanical details consist of the standard N. E. L. A. pin hole shape and threads and an assorted arrangement of line and tie wire grooves, to accommodate various sizes of conductors. Thickness of porcelain, more than commensurate with

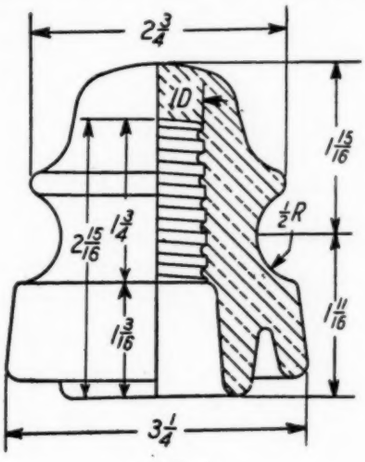


FIG. 1.

puncture requirements, is necessary for manufacturing purposes and to provide mechanical strength. The insulators, shown in Figs. 1 and 2, illustrate the smaller and larger of the designs in this class. The upper range in size is limited by decreasing efficiency in flashover distances and more especially by rapid physical deterioration of integral large masses of varied section. This action is tied up with the coefficient of expansion and results in early mechanical failure in service.

The multipart pin type designs, Fig. 3, cover a voltage range from 13 KV to 88 KV. These designs are built from separate parts into a complete assembled unit. The number of parts commonly used is from two to four. Insulators of this type are used for line insulation, switch and buss supports and in other sub-station construction. In power line application the mechanical loads are compression, cantilever and tension. In switch use torsional loads are added. Provision for the tension component in the design gives ample strength for the other mechanical loads. In this the important mechanical feature is the distribution of material in the body section. The present day insulators are fashioned, in this respect, upon the patented Faradoid principle. This is essentially an electrical factor but incidentally provides desirable mechanical advantages. It permits the distribution of the body sections most effectively, so that thick unbalanced parts are replaced by thin uniform sections. This construction aids in the equal distribution of the load stresses through the unit. This is, without doubt, a vital factor in the life of an insulator, as experience indicates that failures are more attributable to this mechanical detail than any of an electric nature.

The insulators are made from separate parts for two main reasons. One is the economics of manufacture and the other is the inability of integral large

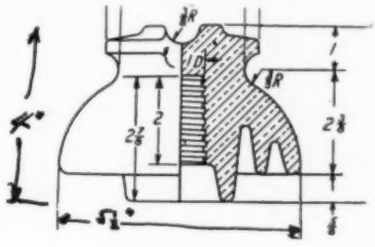


FIG. 2.

masses of such shape to remain intact on account of differential expansion. It has been determined, using the figures given for coefficient of expansion and modulus of elasticity, that in a uniform section a tensile stress of 3,000 pounds per square inch occurs with a temperature change of 180°F., and that with unequal sections a stress factor as high as three occurs, giving this value with a change of 60°F. The effect of differential expansion in a unit mass of such shape as the multipart pin type design is to set up severe and destructive tensile stress in the surface layers. This is, unfortunately, the weakest mechanical characteristic, and as there is little or no yield in the material, complete mechanical rupture occurs.

In the multipart designs, this point merits consideration in the assembly of the parts. From the

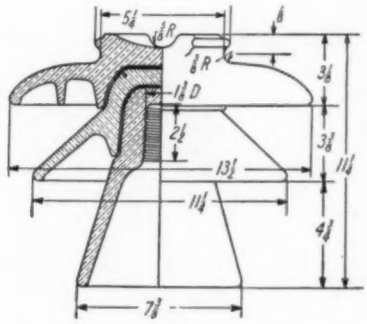


FIG. 3.

many materials tried for assembling the parts, Portland Cement remains the most preferable and widely used. Not that cement is ideal, but because at present a better material is not known. In addition to expansion effects in the insulator, a tensile stress on the overlapping parts at the joints results from the volume changes that occur in the cement. The early multipart designs had the cementing surfaces grooved or scored to furnish engagement with the cement. This gave a very rigid assembly, approximating one of integral mass with relatively short service life. This led to the patented sanded surface-resilient film

joint which provides resiliency in the assembled unit. Steam setting of cement, also patented, gives increased hydration, and a more stable condition. These improvements were made a number of years ago and resulted in designs which in general are mechanically stronger than other parts of construction with which they are used.

The cap and pin suspension insulator is the type used to the largest extent for high voltage transmission. It overlaps the multipart pin type from 66 KV to 88 KV and is becoming more favored for these voltages. Coupled in strings, additional units can be added to meet special isolated conditions, giving greater flexibility than the pin type.

The suspension unit comprises a porcelain shell and a metal cap and pin. Two general methods of interconnecting the units are used, one is the clevis type, so called from the two projecting parallel lugs from the cap to receive the tongue on the pin of the adjacent unit. The other is the ball and socket type being distinguished by the socket on the cap to receive the ball on the pin. The classification is further divided on the basis of mechanical rating and

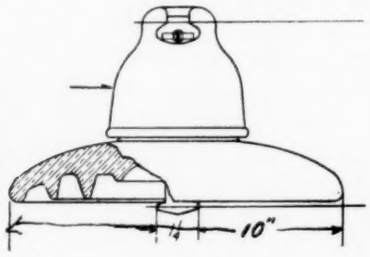


FIG. 4.

dimensions. Three active sizes are those at the approximate values of 10,000 pounds, 15,000 pounds and 20,000 pounds. Units for special application have been manufactured with a 30,000 pound rating. All of them, however, embody similar details of construction.

The mechanical strength is worked out in the details of hardware design, and cross sectional area and length of porcelain head section. Again the tensile strength of the porcelain is the controlling characteristic in the mechanics of the design. Electrical requirements limit the overall dimension of height, and increasing the cross section does not necessarily increase the mechanical strength. To obtain the best working efficiency of the porcelain the ratio between height of head section, depth of pin hole, diameter of pin hole and thickness of porcelain under mechanical load is such that the component of tension should be low and that of compression and shear high. Increase of thickness of material above defined limits, lowers the angle of the compression component, changing the moment arm of the load and increasing the tension component. This results in a lower mechanical strength. The polarized light or photo-elastic study of suspension insulator designs demonstrates these features nicely.

The design details of the cap and pin also influence the strength of a given design of porcelain, those of the pin being the most important. The cap and pin transmit equal loads, that of the pin to a much smaller area of porcelain than the cap, hence higher stress per unit of area in the pin hole.

The cap is made of malleable iron, or drop forging hot dip galvanized. Good malleable iron will develop the ultimate strength of the porcelain and additional strength in the lugs of the forged cap does not improve the performance of the assembled unit. The cap fits neatly over the porcelain head, the shape and location of the gripping details determining the distribution of the load through the cement to the porcelain.

The pin is usually a forging, also galvanized. More variety, perhaps, can be found in the design details of pins in use, than in other features of the insulator. The arrangement of shoulders and angles of gripping surfaces that gives the most uniform distribution of the load to the porcelain, is preferred. These factors can be determined by test.

The short time test in a pulling machine to determine the ultimate gives an indication. The combination of this test with voltage applied, known as combined Mechanical-Electrical test, gives more information; but combining this with time into a time-

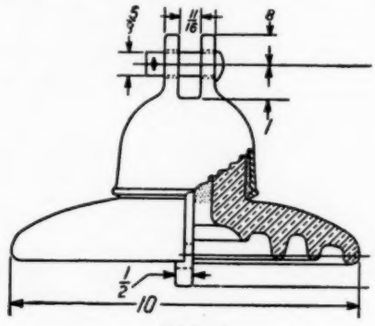


FIG. 5.

load test under continuous potential or periodic check gives conclusive data.

The combined Mechanical and Electrical test gives the load at which the unit fails electrically, the failure being caused by mechanical rupture of the porcelain and the voltage acting as an alarm to indicate the occurrence. This shows the ratio between the combined and ultimate strength values of the design. A high combined value and a high ratio are desirable, but the results from such a test may be misleading, as the design may be such that a large tension component brings a simultaneous failure, giving a ratio of unity. The time load test is more effective in determining these comparisons. On it the insulators are usually connected in strings to a constant mechanical load at from fifty to seventy-five per cent of the ultimate strength for a period of nine to twelve months. Voltage application discloses failure. Data from these results are more indicative of the efficiency of the design, for in the final analysis, the insulator as a whole is no stronger than its combined strength.

The assembly of the suspension, like the multipart pin type units, is also an important factor in its service life. The failure of the first suspensions was caused by the effects of differential expansion between the metal and porcelain parts. The present assembly is made with the sanded surface and steam setting of cement. It is the practice to insert a spacer between the bottom edge of the cap and the porcelain shell, which is removed after assembly, thereby providing a freedom for expansion of the

cap, without danger to the porcelain shell. Resiliency is provided in the pin hole by an elastic material between the end of the stud and the bottom of the pin hole and the resilient film over the sides. These improvements in assembly afford relief against the expansion stresses and have overcome the cause of failure in the early designs.

In considering the pin hole assembly, some of the foreign practices are of interest. One construction known as the "V" ring type or modifications of it comprises a porcelain shell, having an undercut groove at the outside base of the head and an enlarged pocket at the closed end of the pin hole. Instead of cement, the cap is attached to a split ring fitted into the groove and the pin is assembled with a ring inserted in segments between the shank and the porcelain and held in place by pouring in alloy or by a soft metal ring that yields to the shape of the shoulder between the pocket and the sides of the pin hole. Both arrangements give a loose pin assembly. One of the disadvantages of this construction is the manner in which the mechanical stress is localized at the shoulders with resultant low electrical load value. This type of constructiton of the porcelain shell has been adopted in this country, to some extent, with the cement assembly, in an effort to obtain high ultimate mechanical strength. This appears to constitute a hazard for which the best resilient features can hardly be expected to compensate.

Years of successful service have demonstrated the merits of the principles of the normal design. These same principles may be retained in the design of the higher strength units. These are also showing good service records and there is assurance of having reliable suspension insulators to keep pace with the other progress in high voltage transmission.

*Dirt On Insulators**

By G. W. LAPP†

SYNOPSIS—Various kinds of surface contamination are considered and their effect on the ability of an insulator to carry the line voltage without interruption. From the behavior of certain types of surfaces there is developed a general principle of exposure and uniformity as the chief requirements for effective surface conditions. A series of insulators is described embodying this principle of uniformity.

UNFAVORABLE CONDITIONS

On most power systems there are certain localities in which insulators become coated with dirt and give trouble. A bad condition is usually found along the seacoast where salt spray is picked up with the wind and deposited on insulators, accumulating a coating that is soluble in water. If rains are regular the coating is usually washed off sufficiently to avoid serious trouble but in case of a long dry period the layer of salt becomes thick. When the first drizzling rain wets this deposit it becomes very conductive and causes flashovers until a good soaking rain dissolves and washes it off.

Sometimes alkali dust or some mineral dust is picked up and blown onto the insulators making a more firmly adhering, less soluble coating which necessitates washing off by hand.

These two elements, sea salt and dust, are the principal natural ingredients that are encountered over long stretches of transmission line. There are all degrees of severity in their occurrence. Along the sea certain combinations of deposit and dripping fog will cause flashovers in a week if washing is not done; in land locations of extreme dust storms and heavy fog and dew cleaning has been required every other night to maintain service during certain seasons.

Contamination from industrial dirt includes general smoke and dust of cities and railroads that warrants the use of insulators rated as high as two to two and one-half times phase voltage. Part of the reason for such high factors of safety is a willingness to use a larger insulator to avoid outages even in clean or standard atmospheric conditions.

More severe conditions of industrial dirt are met around chemical plants where corrosive as well as conductive coatings occur and corrosive gases attack metal parts. These are unusual conditions affecting a few insulators. Very special conditions are met in electrical precipitator installations covering a wide range of temperature humidity and dust.

Cement mill deposits are sometimes cumulative and highly conductive when fresh deposits or deposits underneath the insulator are wetted.

Steel mill insulators in various places have the foregoing difficulties to meet in maintaining service and in addition they have in the coating particles of iron oxides serving to make the deposits of lower resistance and more adherent to the surface.

Dust from the yard furnishes the usual variety of soil particles and blast furnace dust. Locomotives add coal smoke with its carbon and sulphur. Floating scale from the rolling mill and clouds of dust from "Slips" in the blast furnace contribute conductive particles of iron oxide. The blast furnace dust further increases the supply of lime stone and carbon from the coke. A near-by cement plant may help to form a conductive crust on the insulator.

In a given plant one or more of these factors may predominate to characterize the deposit. In some places a smooth black coating is firmly attached; in other places a rough rusty crust. The coatings are usually thinner and less conductive on top outside surfaces that are cleaned and washed by the winds and rains; crusts are thicker and more loosely attached on the sheltered surfaces.

Severity and importance of service around steel mills are indicated by the size of insulator that en-

*Presented before Pittsburgh District Section, A.I.&S.E.E., March 3, 1928.

†Chief Engr., Lapp Insulator Co., LeRoy, N. Y.

gineers have felt justified in using. We find insulators for 6600 volt circuits, for example, from a rating of 25,000 volts to a rating of 35,000 volts, and cases as high as 45 kv. a factor of 400 to 500 per cent, in an endeavor to secure freedom from flashover and frequent cleaning. Even then cleaning is necessary as often as every few months.

FAVORABLE CONDITIONS

Favorable factors exist to help offset the foregoing recital of gloomy facts that are familiar to Electrical Engineers in the steel industry. Most situations have saving features that permit things to operate. In the case of deposits on insulators, if all the above factors occurred simultaneously to a high degree there would be much more trouble in holding the voltage on the line.

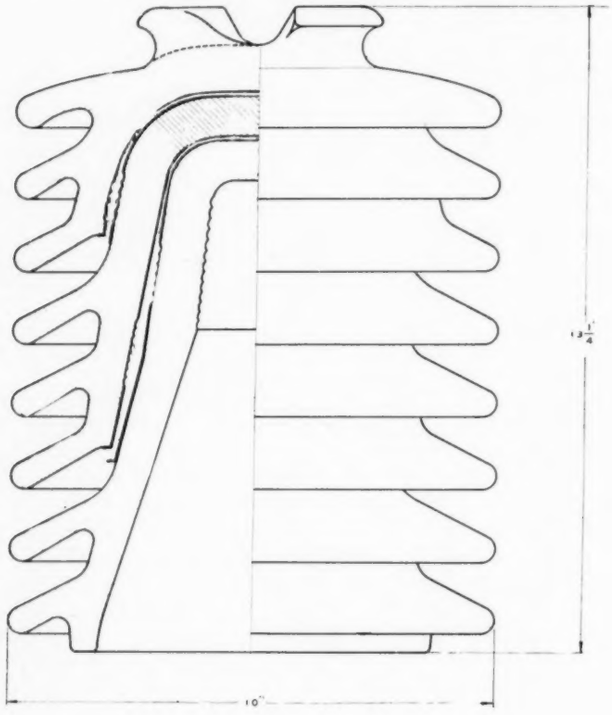


FIG. 1.

Some of the favorable factors that decrease conductivity of surface coatings are:

Particles deposited have limited conductivity in themselves. Metallic particles are in the form of oxides or quickly become oxides. Most mineral particles are good insulators when dry. Conductivity over a dry insulator does not cause trouble even with an excessively thick coating.

Particles have such extremely small contacts with each other that they do not form an unbroken continuous path. They are bound together by organic or mineral soluble binders that will not stand the leeching, soaking action of rain water. Clean silica sand in a clean atmosphere cannot get a hold on a glazed surface.

Ordinary aluminum paint consisting of fine flakes of metallic aluminum mixed with a lacquer has surprisingly little conductivity. The particles do not touch each other to form continuous paths.

Coatings are made less conductive by the same water that makes them conductive. Conductivity is almost entirely electrolytic, that is, it is the conductivity of water holding substances in solution. When plenty of pure rain water is supplied it will leech out those soluble elements of a deposit that cause conductivity and adhesion of the coating. If the surface is on top or exposed to driving rains or if water can drain down over it the resistance will be kept up to a satisfactory figure. Rain water will disintegrate cement by dissolving out essential soluble elements.

It has been observed that in conditions of contamination causing frequent flashovers it is the vertical strings of suspension insulators that let go

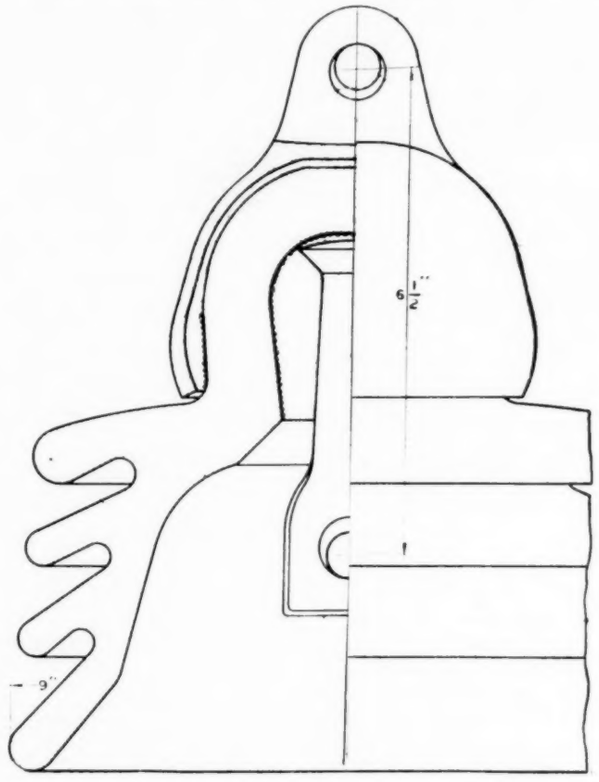


FIG. 2.

and not the horizontal strings. Horizontal strings stay cleaner because they are more exposed to washing.

The effectiveness of rain water in cleaning a dirty automobile surface illustrates the point. Skylights and glazed surfaces exposed to beating rains come back bright and shining. Even the rough surfaces of buildings exposed to rain and wind are in striking contrast to the dirtiness of sheltered areas. Rain water on a clean insulator does not cause trouble.

"FOG" TYPE INSULATORS

The design of an insulator to fulfill the requirements of a leakage type for specially dirty conditions should have its surfaces open and exposed to the cleansing action of winds and rain. It is true that such exposed surfaces will also be open to the dirt. Dirt cannot settle as readily on wind-swept surfaces while wind and rain can clean off to best

advantage surfaces upon which dust settles in periods of quiet atmosphere. It is futile to attempt to keep clean and dry surfaces that are concealed underneath or inside because in time eddy currents will deposit dirt and blowing mists will find their way to wet them without the chance to wash out their accumulating conductivity. This is the first principle of design, exposed surfaces.

The second principle of critical importance is the matter of uniform resistance from end to end of the leakage path. By uniformity of resistance under all conditions of service the leakage path will experience a uniform drop in potential and a uniform dissipation of wattage loss due to the leakage current flowing over the leakage path. If we can construct a uniform leakage path of this kind it will be free from hot spots at which the leakage current dries up the moisture and concentrates the drop in voltage. At these hot dry spots in a non-uniform path low resistance arclets appear and quickly spread to consume the entire path. Hot spots may be all right in the intake manifold of a gasoline engine but they should not be encouraged in the leakage path of a transmission line insulator.

Elements of uniformity of path are:
Uniformity in width of path.
Uniformity in dirtiness.
Uniformity in wetness.
Uniformity in dryness.

To the degree that these conditions are true the total path will resist being blown up into a short circuit arc. To form an arc the leakage current

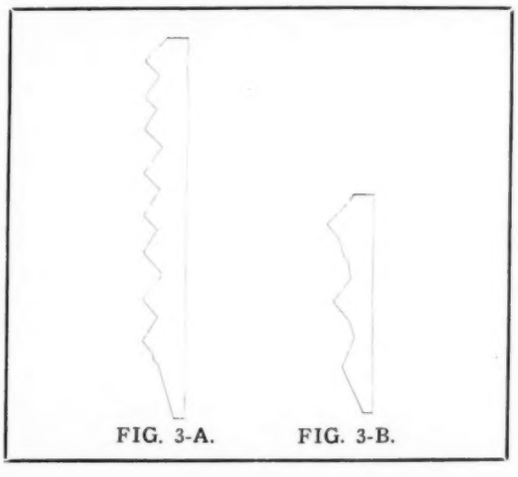


FIG. 3-A. FIG. 3-B.

must transform its wetted path that carries the current through liquid conductivity. It must dry up the liquid and heat the adjacent air to a high temperature before it can establish itself as a gaseous arc.

To illustrate these two principles of exposure and uniformity of the main leakage path as applied to the actual insulator structure consider the various figures.

Figs. 3-A and 3-B shows the development of surface between two vertical planes through the axis of a "Fog Type" insulator compared to the surface similarly cut out on a conventional pin type insulator. Note the greater uniformity in width which is one factor of uniform resistance. This variation in width is directly proportional to variations in radial distance from the axis to the surface. The diagram is made up by plotting vertically distances along the leakage path from tie wire to pin and horizontal distances are taken as the corresponding radii for each point.

Not only does this large variation in standard insulators cause a great variation in resistance due to changes in width of path but it causes extreme changes in dirtiness and wetness by the sheltering effect of the watersheds. After an insulator is dirty there may be one of a great variety of conditions present. At the beginning of a storm the outside of

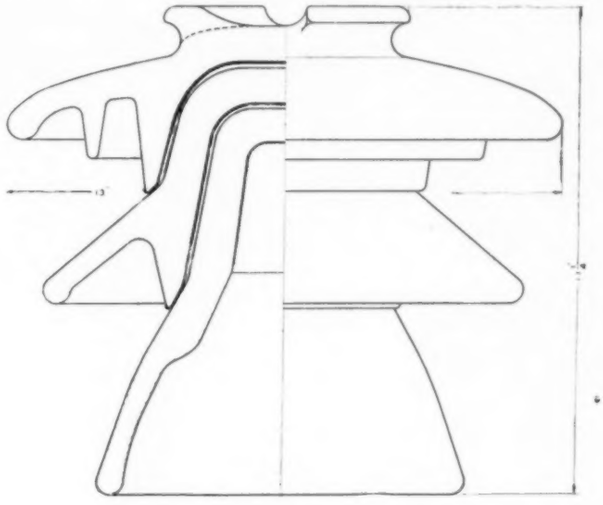


FIG. 4.

the shells are wide and wet and less dirty while the surfaces toward the center are narrow and more dirty and dry and more resistant. After a while, in a driving rain, the surfaces underneath become wetted and lose their resistance. In drying off the dirty surfaces hold the moisture and the cleaner outside areas become more dry and resistant in spite of their greater width. It is evident that the less uniform the structure the greater the chances for an indeterminately large variation between the parts of the surface in their ability to carry leakage current quietly.

The design having for its principal leakage surface corrugations with small radial depth exposed as they are on the outside of the insulator has a better chance; to clean itself or to acquire a more uniform coat of dirt; to become more uniformly and simultaneously wetted and to become more uniformly and simultaneously dried off.

It is difficult to blow up a path of current that is plentifully supplied with water. A large energy load may be carried by a hose or stream carrying a rapid flow to take the heat away. Some tests give higher wet flashover if the insulator is sprayed upward under the shells as well as at a downward angle on the tops.

It may appear that a cylindrical rod is an ideal form for an insulator on account of its uniformity. But even aside from its prohibitive length a rod insulator is subject to streaking while small corrugations offer an opportunity to redistribute potential and current and to break up drip. Without sacrificing much uniformity of width small cor-

rugations serve to condense an unusual leakage length into the space required by dry flashover distance.

This ability to secure liberal length of leakage path of a uniform nature without increasing the flashover distance is a matter of importance in connection with substation equipment. If it is desired to decrease the liability to leakage flashover and a larger standard type insulator is used the impulse flashover voltage is raised and it may then throw the flashover into the station equipment. By the use of the "Fog Type" insulator the leakage or dirt condition is met without raising the impulse flashover voltage. It is an established fact that a dirty insulator even when wet requires about as high an impulse voltage to flashover as does a clean dry insulator.

These new designs of pin and suspension "Fog Type" insulators provide greater leakage distance with a more effective distribution of surface. They are of smaller diameter than corresponding standard types.

*Protection From Flashovers**

By H. B. VINCENT†

WITH the art in its present stage, engineers very rarely equip their transmission lines with insulators which under normal operating conditions do not have sufficient insulating value.

However, whether this insulating value is sufficient under abnormal conditions depends on quite a few variable factors.

In general, these factors consist of the cleanliness of the insulators, magnitude of surges due to switching or other disturbances originating in the transmission system and to lightning.

Any one of these factors occurring may cause the insulators to flashover depending on whether the flashover voltage of the insulators is equal to or less than that of the disturbance.

In the earlier days of high voltage transmission, most of the insulator trouble was due more to puncture than flashover—I have in mind about the year of 1905 when the highest operating voltage was in the neighborhood of 60 kv.

As the result of these troubles the specifications were altered such that the puncture value was made higher than the flashover values, so that together with the natural improvement in manufacture it is now a rare case when a pucture occurs.

The practical elimination of punctured insulators however, has not removed the possibility of insulators becoming damaged when flashover occurs as the heat of the power arc breaks the porcelain in which case the flashover and in some cases the puncture value is thereby decreased.

Probably the earliest protective device applied to pin type insulators was a ring of approximately ¼" round iron having a diameter of about twice the diameter of the insulator skirt.

The purpose of this ring was to direct the arc away from the skirts when a flashover occurred, and not to prevent the arc from originating over the insulator.

This device was not extensively used due probably to the fact that newer designs of insulators were more rugged and of higher flashover value.

With the beginning of the operation of lines with voltages above 60 kv. and employing the suspension type of insulator apparently very little concern was given to the necessity of protecting the insulators from the flashover arc, although it was realized that trouble would probably be experienced from the burning of the conductor from flashovers as the several insulator manufacturers included an arcing horn in their hardware accessories.

This arcing horn consisted essentially of a piece of malleable iron ⅜" in diameter in the shape more or less of a semi-circle with a 15" spread. The one for the top being fastened either to the cap of the top insulator or to the supporting hardware, that for the bottom serving as the clamping strip or "keeper" of the conductor clamp.

These horns have not been universally used due, no doubt, that as designed and installed they reduced the flashover value of the insulator string (in the order to 70 to 85%) and based on 60 cycle flashover sufficient units were installed to give good factor of safety.

As the progress of the transmission art has developed and it has been possible to obtain laboratory tests simulating lightning more thought has been given to impulse voltage as distinguished from the 60 cycle and high frequency voltages.

As might be naturally expected there has not been an unanimous agreement with respect to all the causes and effects of these so-called transient voltages. Consequently this has resulted in the offering to the user of several types of protective devices by the several insulator manufacturers and as they are represented on the program today I am assuming that they, like myself, will not be too modest to mention the principle at least of the functioning of their device.

In our studies and research on an insulator protective device we have had this in mind:

Porcelain as now manufactured is not immune from damage due to a heavy power arc.

The device should decrease the flashover value of the insulator string as little as possible.

It should direct the power arc away from the insulators.

Have a minimum arcing distance.

Its contour should be such that it should invite and possibly cause the arc to extinguish itself be-

*Presented before Pittsburgh District Section, A.I.&S.E.E., March 3, 1928.

†Manager, Field Engineering Service, The R. Thomas & Sons Company, East Liverpool, O.

fore the automatic tripping of the line circuit breaker.

It should be rugged enough to withstand the burning due to the power arc.

The arcing distance should remain constant even after such burning occurs.

Have if possible interchangeable parts to simplify replacements, also some flexibility with respect to adjusting arcing distance.

All of the above has been accomplished by the employment of an arcing tip having a combination of both the sphere and needle characteristics.

Laboratory tests have indicated that to overcome the cascading due to impulse voltage a regrading of the voltage across the insulator string is necessary.

As dirt and moisture may affect the distribution, all conditions which may be met in practice cannot be duplicated in the laboratory.

Laboratory tests have indicated that by the employment of an arcing tip as above mentioned cascading from impulse voltage can be eliminated to a large extent.

The fact should not be lost sight of that theory and laboratory tests are not conclusive; this has been rather forcibly demonstrated within the past year by actual power tests where it was found that the action of wind or even a breeze had a considerable bearing on the efficiency with which a protective device prevented the breakage of the insulator porcelain from a power arc.

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*Protection of Transmission Lines**

By D. H. ROWLAND†

IN the transmission of large amounts of electrical energy continuity of service is of the utmost importance. There is no doubt that one of the greatest problems which confronts the electrical engineer in this connection, is the flash over of insulators due to line surges. Although switching, birds, and other unknown factors are the underlying cause of many disturbances it is now readily conceded that induced lightning voltages account for approximately 90 per cent of the trouble.

If a charged cloud passes over or near a transmission line there is a static charge of polarity opposite to that of the cloud induced upon the conductors since the gradual leakage over the insulators or through the transformers allows the equal and opposite charge to flow to ground. When a lightning stroke occurs the static field collapses and the charge on the conductors forms into two waves which travel along the line in opposite directions, with velocities approaching that of light.

The speed of lightning discharge and the impedance of the line controls the steepness of these waves which in any case is very great. Because of the time necessary for air to ionize before breaking down, steep voltage waves of this character may be considerably above the crest 60 cycle line voltage and yet not cause a flashover. In such cases the waves as they progress become attenuated and may gradually dissipate themselves in corona and I^2R losses or ground through lightning arresters.

It has been shown by Mr. F. W. Peek, Jr., that the magnitude of the induced voltage depends directly upon the height of the conductors above ground since they assume the potential of the air through which they pass. For the purpose of calculation an approximate gradient of 100 kv. per foot may be used. Thus for a line 30 feet high the maximum possible induced surge would be 3000 kv. A gradient of this magnitude occurs only when the cloud is directly over the line. More frequently the induced surges correspond to gradients of 50 kv. per foot and very often to 25 kv. per foot. It must be borne in mind that even with the maximum possible gradient of 100 kv. the time of lightning discharge may be so great as to materially lessen the induced voltage by allowing the charge to gradually spread along the line instead of being released instantaneously and thus forming practically a perpendicular wave front.

There has been a certain group which has contended that sustained high frequency is the basis for a great deal of flashover trouble. It has however been shown mathematically that the power necessary to maintain continuous high frequency for a long enough period and at a sufficiently high voltage to cause flashovers would be out of all proportion to the energy released at the source of the disturbance. Field data recently collected supports such calculations and the consensus of opinion at the present time is that lightning surges are of a single impulse character or now and then highly damped oscillations corresponding to the natural period of the line.

In designing transmission lines to insure continuity of service there are two classes of devices used in an effort to avoid surge troubles. In the first class belongs that equipment whose function it is to reduce the static charges on the conductors or to alleviate the excess voltages after they have occurred. The ground wire and lightning arrester are of this category. To the second group belong arcing devices and grading shields whose function it is to prevent serious harm to the insulators and phase wires should flashover occur. The grading shield has another feature under lightning conditions which will be pointed out later on.

THE GROUND WIRE

A fundamental electrostatic law based upon Gauss' Theorem is that no electrostatic field due to external influences exists within a closed conductor. If it were possible to completely enclose a transmission line by a perfectly conducting shield light-

*Presented before Pittsburgh District Section, A.I.&S.E.E., March 3, 1928.

†Research Engr., Locke Insulator Co., Baltimore, Md.

ning troubles would be absolutely eliminated. This of course is impossible and a relatively simple compromise to the perfect condition is obtained by using ground wires.

Such wires materially reduce the excess potentials induced on transmission line conductors. Various investigators have found that the reduction that may be expected from one wire is in the neighborhood of 40 per cent, with two wires 60 per cent, and with three 70 per cent. The exact amount of course depends upon the arrangement of the phase wires and the ground wires with respect to one another. The reason for this reduction lies in the fact that the presence of the grounded wires near the conductors decreases the number of lines of force terminating on the conductors before the cloud discharges. Furthermore they raise the capacity of the phase wires to ground which tends to reduce the potential to ground after the lightning stroke has taken place. Since the increment of protection obtained from the use of each additional wire becomes smaller and smaller the problem of how many to install is an economic question. No doubt from this standpoint the best solution is to allow a few surges of a high enough voltage to cause insulation flashovers to remain on the conductors and to take care of these flash-overs when they do occur by means which will be explained later. Most certainly it is very poor practice to use inferior materials and construction for protective wires as in the past serious short circuits have occurred due to their falling across the power lines. To avoid this the quality of installation should be the same as that of all other parts of the circuit. Proper grounding at frequent intervals is essential to correct operation. In very dry country not only is it very difficult to accomplish this but the induced voltages are higher because in effect the height of the transmission line is its distance above the conducting plane of the earth which is often quite far below the earths surface. Special methods should be resorted to in such cases.

LIGHTNING ARRESTERS

Increasing the insulation on any given line will most certainly decrease the number of flashovers. There is, of course, an economic limit beyond which it would be foolish to go. In addition such practice has a tendency to carry the surges into the substation and damage the apparatus insulation. It is now common practice to protect such apparatus by means of lightning arresters. These devices are arranged to form a path between the line and ground which under ordinary service voltage is of practically infinite resistance but when subjected to an over potential, break down and allow a free flow of current.

It is obvious that in order to prevent a dead short circuit some means must be employed to prevent a power arc from following the surge. One of the most successful arresters makes use of the valve characteristic of lead oxide which under the influence of heat changes its composition and becomes a non-conductor. The initial charge flows to ground and in so doing raises the temperature of the small units of lead oxide which in turn increase in resistance enough to interrupt the flow of current.

ARCING HORNS

Since it is not economically possible to prevent the occurrence on transmission lines of a certain number of surges sufficiently great to cause insulator arc overs it is imperative that some means be adopted to prevent those arcs which do take place from breaking the insulators or burning the conductor before the circuit breakers have time to operate. This may be accomplished to some extent by the use of arcing horns. Metal projections are added at the top and bottom of the insulator string in an effort to hold the arc away from the procelain material and the conductor. There is no doubt that some good work has been done by such devices. In a number of cases, however, it has been found that the arcs paid very little attention to the arcing points unless they were placed so close together as to materially cut down the flashover voltage of the insulation. Even when the points were adjusted so as to prevent the arc from touching the porcelain with 60 cycle laboratory voltages when placed in actual service in the field the results were disappointing. At the present time the reason for the inconsistency between the earlier laboratory tests and the field experience are well known.

Lightning surges as already stated are single direct current impulses. It has been found that the flash-over characteristics of steep voltage waves are quite different from 60 cycle or sustained high frequency. Since it is established that induced lightning surges are the underlying cause of most serious flashover trouble it is imperative that a great deal of study be given to this class of phenomena if it is desired to design arcing devices which will function properly. Mr. F. W. Peek, Jr., working with the lightning generator, has been able to conduct laboratory experiments with impulses comparable to those found in service. It is impossible here to go deeply into the theory of spark discharge but a few of the most important features must be understood.

It takes an appreciable time for an air gap to break down. Different types of gaps require more or less time according to their physical construction. It is for this reason that steep impulses as much as 2.5 times the effective 60 cycle flashover voltage, may be impressed upon certain insulators without causing flashover. To describe this effect the term "impulse ratio" has been used and refers to the ratio of impulse voltage to 60 cycle voltage necessary to cause flashover. It is obvious that this term cannot be used indiscriminately without defining the wave form of the impulse as this factor has a great effect upon the ratio. If a sphere gap and a needle gap are adjusted so that they will both spark over at the same 60 cycle voltage and are then placed in parallel and subjected to a lightning impulse the former type of gap will be the one to break down even if the needles are brought still closer together. In other words it may be said that lightning takes the fastest path. Another point to be noted is that the wet and dry lightning flashovers of a string of insulators are identical. Bearing these facts in mind it can be explained why arcing devices, the design of which is based upon 60 cycle or high frequency tests, will very seldom operate efficiently in service.

A string of suspension insulators under voltage stress does not distribute the load evenly between

the separate units. This is a well known phenomenon and is due to the fact that the insulator hardware has a definite capacity to ground. Thus the displacement current through the line unit must be enough not only to charge the other units but also the capacities of their hardware to ground. The displacement through the next insulator is the same less the charging current to ground for the hardware of the first unit. Since the internal capacities of the separate disks are identical the voltage which they carry is directly proportional to their displacement currents which means that the bottom insulator will carry much more than its share of the load. Let us consider the action of such a string under lightning conditions. If a surge is impressed upon the string the first unit as explained above is stressed more than the rest and if the voltage is sufficiently large will flashover. This action places the full voltage upon the remainder of the insulators with the result that the second unit will flashover and progressive cascading will extend the entire length of the string.

The path which the lightning takes is faster both on account of the decided inequality in voltage gradient over the string and because the creepage over a porcelain surface has very little time lag. Arcing horns in a case of this character will have little effect unless spaced very close together. The first predatory discharge will invariably cascade along the string and may strip the porcelain skirts. The power arc which follows may or may not be kept from touching the string.

One reason why a test of 60 cycle flashover voltage may show entirely different arcing characteristics lies in the fact that the more gradual application of the voltage allows time enough for corona to form on the lower units thereby raising their capacity and bringing about a more uniform gradient along the string and preventing progressive air breakdown. The air between the horns may then be the first to fail.

THE GRADING SHIELD

In order to keep lightning surges from cascading and at the same time not cut down too far on the 60 cycle insulation it is necessary to employ some method of obtaining a uniform potential gradient over the insulator string. The grading shield is a device designed to accomplish this. A ring of metal is attached to the bottom unit in such a way as to raise the capacitance of the lower insulator hardware with respect to the line. The added capacitance of the shield to the lower hardware neutralizes the charging currents of the hardware to ground and thus makes for a uniform voltage distribution. This equalization of the field increases the lightning flashover of a string of ten units an amount equivalent to the addition of two discs to an unshielded string. Furthermore the redistribution of the field causes the arc when it does occur to jump between the ring and the arcing horns at the top entirely clear of the porcelain. The necessary reduction in 60 cycle flashover voltage is only about 10 per cent. The power arc which may follow the initial surge discharge will under certain conditions blow into the string and for this reason the oval shape of the lower ring is very helpful in allowing the arc to pass around to the leeward side without damaging the insulation.

The grading shield must not be confused with ordinary arcing devices based upon 60 cycle tests. The major premise upon which the device is founded is that it will keep clear from the porcelain and conductor the first transient discharge, which can only be accomplished by proper grading.

Pin type insulators because of the large relative mutual capacity between the porcelain shells as compared to their capacities to ground cannot be graded appreciably by the addition of metal shields. For this reason it is important that the design of such insulators should be, in the first place, of such a character as to distribute the voltage load evenly through the di-electric material. This can be accomplished in multi-part pin types by varying the size of the cement grips between shells and thus changing their capacities much along the same lines as in the design of condenser bushings. When this is properly carried out lightning arcs may be kept away from the porcelain by suitable arcing rings or horns.

There are a number of grading shield installations in service at the present time and the data from the field which after all is the only true criterion of the value of the shields indicates without doubt their great merit.

A recent modification of the grading shield which is now being tried out is the addition of an insulator below the shield. Under ordinary conditions this insulator is shunted by a high voltage fuse. When such a string flashes over the arc forms between the grading shield and the tower hardware. The fuse in series with the arc blows interrupting the current and placing the additional insulator in the string. This prevents the re-establishment of the arc or the formation of an arc over the same string under subsequent impulses.

There is no question but that it is becoming more and more the general practice to use overhead ground wires to reduce the potentials induced upon the transmission conductors, and grading shields to raise the lightning flashover of insulator strings and to prevent damage to the line should flashover occur. The installation of such protective equipment is receiving more attention as past experience has shown that it absolutely pays. Ground connections must be well made. Lightning arresters have been perfected and should be used to prevent surges from reaching the station equipment.

In recent years insulation of all kinds has greatly improved. A great deal more is known about the underlying causes of flashovers. It is only in the last few years that ingeneous devices such as the Klydonograph and Cathode Ray Oscillograph have given information as to the true nature of the surges on power lines and thus enabled laboratory data and field results to be correlated.

It is unfortunate that before this the mystery surrounding the phenomena has led investigators to draw conclusions from laboratory experiments entirely unrelated to the problems. Laboratory results can only be applied to the field when they account for all the factors that are met under service conditions.

This discussion has naturally been somewhat general. It has been my endeavor to give you as complete a picture as possible within the limits of time and circumstance.

DISCUSSION

A. F. Alsaker†: It has been a very interesting afternoon. I was very much impressed by the array of talent you have had here today. In particular, I must pay a compliment to Mr. Lewis for his very excellent paper. I think the central station business, as well as the steel mills, (even if they have only 6600 volt lines) should be thankful to Mr. Lewis for compiling this very excellent information. It is instructive and brings several transmission line problems down to a rather definite basis, avoiding vagueness and guesswork.

C. L. Fortescue‡: I will confine my discussion to the papers presented by Mr. Austin* of the Ohio Brass Company and Mr. Lewis of the General Electric Company. Mr. Austin shows the advantage of making use of the wood pole as insulation against lightning surges. His method of using the wood pole as part of the insulation of the transmission line, however, is equivalent to over-insulating the line and therefore if this type of construction is used measures must be taken either to cut down the insulation near the substations or else adequate provision must be made by the use of suitable lightning arresters to protect the substation against the higher lightning surges that this construction will permit to pass over the line.

One of the most important advantages obtained by the use of ground wires is that they not only reduce the surge potential due to lightning on the line itself but they also reduce the value of the lightning surge potential at the substations. A better type of construction than that proposed by Mr. Austin would make use of ground wires insulated from the pole and connected to earth at the poles by grounding wires so insulated that the full insulating value of the wood poles is preserved. By this type of construction the hazard of pole shattering by lightning is reduced practically to zero and the substations are protected from the high surge potentials to which they are subjected in the type of construction proposed by Mr. Austin. The choice of the type of construction is of course an economic one. The cost of additional protection at the substations and the cost of the serious outages caused by shattering of poles must be balanced against the cost of the insulated ground wire.

As regards Mr. Austin's counter-potential wire, this appears to me to be purely a makeshift to pass the burden of withstanding lightning conditions from the insulator string to the substation. What it means, of course, is that special measures must be taken to reduce the surge potential at the substation either by grounding portions of the counter-potential wire so that the insulator string in this neighborhood will flashover and reduce the burden on the substation, or by increasing the insulation of the apparatus at the substation and using higher voltage lightning arresters, or by a combination of both measures.

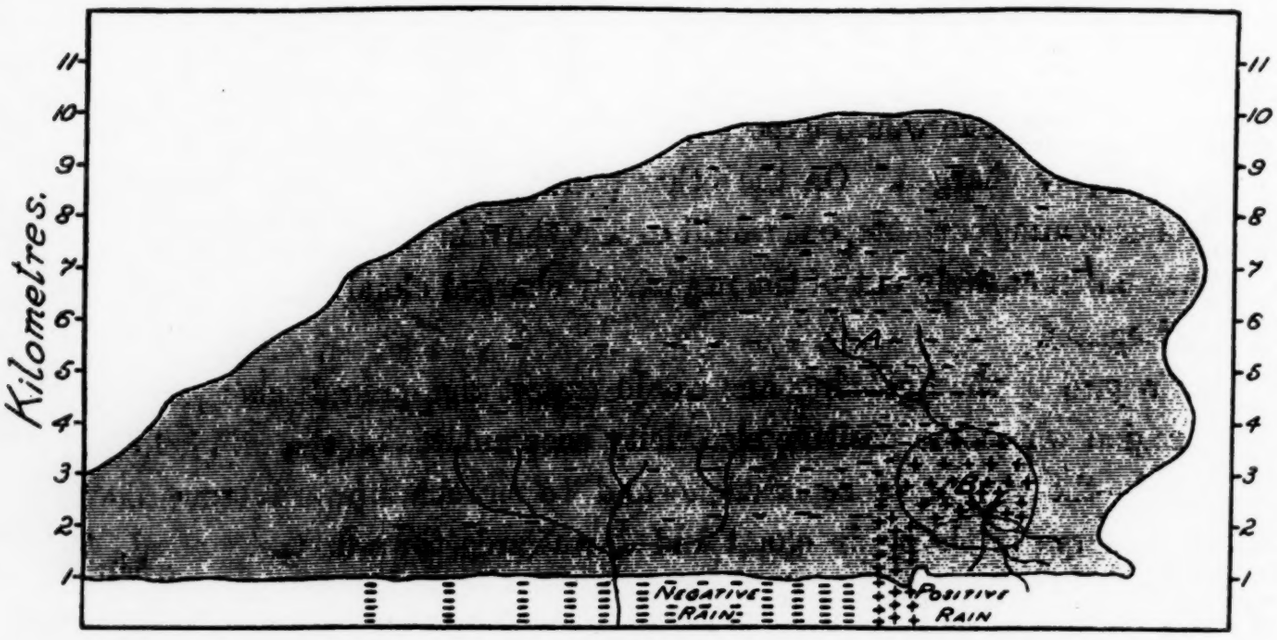

FIG. 1.

As to the nature of lightning discharges, they are never oscillatory. This may be shown by referring to Fig. 1. A thundercloud is of enormous volume and may be charged to potentials of from 100 to 130 million volts. When a lightning flash takes place it starts from the earth and when it reaches the atmosphere of the cloud, due to the saturated condition of the atmosphere, ionization cannot be sustained so that the discharge is retarded and is broken up into a number of small branches which penetrate a relatively small volume of the body of the cloud which it discharges. This small portion of the cloud is discharged by these streamers and since, on account of the super-saturated condition of the atmosphere of the cloud, the charges

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*Mr. Austin's paper was not received for publication at the time of going to press.

from the remaining portion of the cloud can only move slowly, the potential of this portion is reduced to such an extent that it cannot sustain the arc to ground and therefore the single impulse only passes to earth. After the discharged portion is built up again to its original potential a second discharge may take place over the same path and this may be repeated a number of times. The interval between the successive discharges being large as compared to the duration of the impulse itself.

If there is a transmission line in the neighborhood of the thundercloud there will be an induced charge on that line and when the lightning flash takes place the induced charge will be released and a surge will travel over the line. If the transmission line is of great length the surge will go on travelling over the line indefinitely until it is reduced to zero. However, if the transmission line is very short and is open at both ends, when the surge reaches the end of the line it will be reflected positively, building up to twice its incident value. The reflected wave will travel back towards the origin of the first surge and when it reaches the other end of the line it will again be reflected positively; consequently, an insulator string at any given point on the line will be subject to a unidirectional, highly damped series of impulses, the wave length of which will be equal to the length of the line. Similarly, if the transmission line is grounded at both ends, a highly damped oscillation will be set up which will have a wave length equal to twice the length of the line. In this manner only can you get an oscillatory discharge over an insulator on any transmission line, but usually this condition does not exist because in the case of low voltage lines each substation is connected to several branches of a network so that the surge induced in one branch of the network, even though this branch may be considered as a short length of transmission line, when it reaches the substation passes into another branch and this takes place indefinitely through the network of transmission lines. In the case of a loop which is a very common type of network used with low voltage transmission lines, the surge initiated in one portion of the ring will be propagated around the ring and keep on circulating until reduced to zero. Hence, in practical experience there is no approach to an oscillatory condition on transmission lines due to lightning and this is borne out by actual field experience with the klydonograph.

The Westinghouse Company has been carrying out investigations on lightning during the past three years with the klydonograph. During the previous years attempt had been made to do the work with a series of sphere gaps set for different values but the apparatus was too cumbersome for use in the field so it was decided to develop something that could be conveniently used in the field and give reliable records of lightning. The klydonograph was the result. With the klydonograph we have made investigations of lightning in many places in the United States, and although we have taken several thousand klydonograms we have never yet found anything of the nature of an oscillatory discharge due to lightning. Any oscillatory discharges that have been observed by the klydonograph have been found due to some such condition as an arcing ground.

In regard to the attenuation of surges when passing over the transmission line, the attenuation factor depends upon the resistance of the transmission line which must also include the resistance in the earth portion of the circuit and the leakage factor due to corona and leakage over insulators. The attenuation factor is an exponential term, the exponents being a function of the above quantities and time. We may obtain some idea of the attenuating action by remembering that the current surge is exactly in phase with and proportional to the potential surge so that the resistance drop will reduce the potential as the surge progresses along the line. We thus have a function which causes a reduction in itself depending upon its own value, the reduction factor will therefore be an exponential function which is known as the attenuation factor. In the case of a transmission line protected by ground wires the effect of the ground wires is to reduce the inductance of the line with the earth return and increase the resistance of the earth return path. Therefore, the effect due to the resistance is increased. Again, the corona due to the surge potential induced with the ground wire will be greater than the corona due to the surge potential induced in the transmission line without the ground wire, on account of the fact that the potential reduction is not so great as the reduction in effective distance between line wire and ground brought about by the ground wires. Consequently, the effect due to the leakage factor will also be increased. The net result is a decided increase in attenuation due to the addition of ground wires.

As has been stated before, the ground wire not only protects the line but also protects the substation. It is a poor argument that the ground wire is of no use because it has been known to fall down and short circuit the line. I am surprised that any engineer would make such a statement. If a ground wire causes trouble because it falls down and short circuits the line, it is by reason of faulty construction, that is to say, a poor engineering job; it is not the fault of the ground wire. The ground wire will always afford a certain measure of protection, in some cases it will mean the difference between economic success or failure for transmission lines. I have seen statistical reports where the reduction in outages due to the use of one ground wire has brought about a reduction of outages per 100 miles per year of the order of ten to one as compared to an unprotected line.

The values given by Mr. Peek for the reduction effect due to ground wires appear to me to be too optimistic. Calculated values obtained by us show a reduction of about 35% for one ground wire and 45% for two ground wires. I shall be glad to have Mr. Lewis explain the cause of the discrepancy between Mr. Peek's observed values and the values obtained by mathematical calculation. With the horizontal construction of transmission lines, ground wires can be arranged to give very effective protection and there is a further advantage due to the fact that the average height of the transmission line is much lower with this type of construction than with the vertical type. In the vertical type of construction ground wires cannot be arranged so effectively. Returning now to Mr. Lewis' paper, I think that he has presented a very fine paper for this Association. However, I told Mr. Lewis after

the afternoon session that, while in general, we were in full accord, there were some points on which we would not agree. One of these points I have already discussed, namely the discrepancies between Peek's laboratory values for the protective effect of ground wires, and values obtained by computation. The other point on which I disagree with Mr. Lewis is in the wave form of a lightning surge. I do not know how Mr. Lewis or Mr. Peek deduced what they call the "standard impulse wave" which Mr. Lewis stated in his paper was taken by them to be representative of the higher lightning surges as obtained by means of the klydonograph and the Dufour oscillograph. We have come to quite different conclusions as a result of our experimental work with the klydonograph and also from the actual surge oscillograms obtained in Sweden with the cathode ray oscillograph and we find that the maximum steepness of a lightning surge is probably not more than 4000 kv. per microsecond, and its duration may be from 10 to 20 microseconds. The actual waves shown by the cathode ray oscillograph last considerably longer than this but the initial disturbance seems to be due to a rearrangement of charges along the line during the initiation of the lightning flash and have no bearing on the actual induced surge. We do not set up any standard wave; what we say is that the lightning surges that will cause trouble on transmission lines are those that have maximum values well above the 60 cycle flashover value of the insulator so that the important factor determining the flashover of the insulator will be the steepness of this surge since its maximum value will be well above the flashover point of the insulator. So we draw a curve as shown in Fig. 2 where the radiating lines represent surges of different steepnesses whose maximum value is well above the flashover value of the insulator. We then obtain either by test or calculation the curve shown which gives the impulse ratio of the particular insulator for each value of wave front.

You will note on the diagram the horizontal line which is the 60 cycle flashover line. In an insulator the 60 cycle flashover takes place when the field surrounding the insulator reaches a certain critical condition brought about by ionization by collision. When this stage is reached ultra violet rays are emitted which cause heating and local concentration, causing thermal dissociation of the air molecules. As a result of this thermal dissociation the breakdown takes place along certain paths which are shown by intense white streamers which travel from electrode to electrode at a certain speed which depends upon the average potential gradient between the electrodes. When these streamers have travelled the full distance between electrodes, flashover takes place. The computation of the time required for these streamers to initiate and move from electrode to electrode can be carried out with a fair degree of accuracy so that curves shown in the figure can be actually calculated and the calculations check up very closely with the observed values.

When a lightning surge just reaches the 60 cycle value no flashover takes place, however, if it reaches the 60 cycle value at a certain time and goes slightly above it, being reduced within a definite time from the point where it originally crossed the 60 cycle value, if this definite time is greater than the time required for the streamers to move across the electrode, the insulator will flashover in which case the impulse factor will be unity. For very slow surges the impulse factor approaches unity. For very steep surges the impulse factor may be two or more. Therefore, you cannot say that an insulator has a certain impulse factor to lightning surges since, as an actual fact, the impulse factor may be anything from unity to values of two or three. In fact, the actual time required to breakdown a long string of insulators is of the order of only 0.2 of a microsecond and the time of a lightning wave may be from 10 to 20 microseconds. Therefore, it should be plainly seen that the impulse factor must necessarily be very variable, depending upon the type of surge to which the insulator is subject.

A further thing I wish to emphasize is that the true criterion of the insulator strength is the 60 cycle flashover value. It is the 60 cycle flashover that determines the number of outages that will occur on a transmission line. All lightning surges except those whose maximum values just fall below the 60 cycle flashover value of the insulator will flashover the insulator. The importance of impulse factor is to determine the amount of a steep and severe lightning surge that will pass by the insulators after they have flashed over, because these surges will eventually reach the substation and they must be taken account of in the protective measures for the substation. However, since these surges, on account of the chopping effect of the insulator flashover, are of very short duration, they are not in general a great hazard but have to be given consideration where their effect is likely to cause trouble. The most important lightning surges to consider in the protection of substations are those that almost flashover the insulator, that is to say, those that just reach the 60 cycle flashover value of the insulator. Those surges have a great deal of energy and have the potentiality for causing a great deal of damage. High impulse ratio has no value whatever in preventing outages, all it does is to let you know how much will get by your insulator string when it flashes over. Theoretically, the ideal insulator string would be one that had a sufficiently high 60 cycle flashover value and impulse ratio about unity for all lightning surges. In other words, one having sphere gap characteristics.

The advantage of ground wires in protecting the transmission lines will now be quite apparent. The advocates of high insulation such as our wood pole construction friends, advocate insulation to meet lightning. The ground wire enthusiasts advocate lightning to meet insulation. In other words, you can raise your insulation and reduce your outages, you can lower your lightning and reduce your outages. Of course, the two may be combined, that is to say, the insulation of transmission lines can be increased and at the same time the surges that it is subject to can be reduced by ground wires. The advantage in protective measures on transmission lines is that the surges coming into the substations are also reduced.

In this discussion I have theorized quite a little bit but I am very much in accord with what Mr. Lapp said in his paper and I may say that while I have theorized I have also kept in mind the practical aspects of the problem. In this problem of

lightning investigation and protection there are so many ramifications, so many things hard to explain, that the proper thing to do is to find out all you can by investigation, research in the field and laboratory, and then make your theory fit the results obtained. This is exactly what we have been doing and are continuing to do. We are going into this lightning investigation as thoroughly as possible. We have done a lot of work with the klydonograph and we expect to do a lot more. We have been closely associated with Dr. Norinder while he was in this country and expect to keep in close touch with him in the future, and while the klydonograph will be the principal instrument for carrying out field investigation work we expect in the near future to do some work with a modified form of the cathode ray oscillograph which will enable us to get certain data on lightning which is difficult to obtain by the klydonograph. The cathode ray oscillograph, however, is too cumbersome an instrument to use for general field investigation so that the klydonograph will always be a leader in field investigation.

W. W. Lewis*: In reply to Mr. Fortescue, I think he misunderstood my reference to standard wave. What I intended to refer to in the paper was the standard wave of the high voltage laboratory at Pittsfield, i.e. Mr. Peek's laboratory. Mr. Peek selected a wave which was very steep and very long in order to have a wave which he thought would be more severe than anything encountered in practice. He has standardized on this wave for tests on insulators and apparatus and thereby gets a fair comparison in the performance of the various kinds of apparatus under impulse.

About the ground wire values: We also have made calculations by the classical methods and have shown protective values somewhat as indicated by Mr. Fortescue. However, Mr. Peek has set up models of clouds and lines in his laboratory and has obtained much better protective values than can be shown by calculation. We believe that the explanation for this is as follows:

Under cloud and lightning conditions the potential gradients at the surfaces of the conductors and ground wire are greatly in excess of the potential gradient required to break down air. The air is broken down and corona formed, thus virtually enlarging the conductor and ground wire and thereby increasing the capacitance between conductors and ground wire. This increase in capacitance reduces the induced voltage and gives a better protective ratio.

A. F. Alsaker†: It may be desirable to mount an insulator straight out if it is used as a conductor support and if you only consider the flashover to ground. But if the insulators are used for supporting equipment where certain safety ratios of flashover are desired, the matter must be considered from an entirely different angle. It is one of these propositions where the consideration of one condition only is apt to lead you astray and arrive at faulty conclusions. A disconnecting switch is primarily a safety device and incidentally a conductor support. If the insulators are mounted straight out, a stream of water will flow from the live top insulator to the bottom insulator during heavy rain and materially cutdown the safety of the switch as a disconnecting device. But this is not the case with insulators mounted at 45°. We know this from actual test. I think the question the gentlemen thought was nicely cleared up is just as dark as it ever was. I wouldn't work on an oil switch protected by disconnects with insulators straight out, unless I knew the safety factor from actual tests.

W. K. Naylor*: What is the advantage in even width of the leakage path when the normal leakage current of an insulator is so low that the narrowest strip of dirt between the line to the ground would carry a relatively large current and the leakage current normally must be very low or power current will follow. What is authority for 60 cycle voltage being limited to 1½ times normal. In one particular case we had a plant operating on 25,000 volts and normal fluctuation in voltage, minute to minute, was from 25,000 to 40,000 volts; so in case of any unusual disturbance, the voltage could rise to 55,000 or 60,000 volts and later protected against that by installing motor generators to reduce the fluctuations.

This is a very unusual case but many cases have been noted where double voltage on lines is not uncommon. On almost any line surges up to four times normal may occur due to causes other than lightning. Double voltage for a few micro seconds probably does not injure any apparatus on the line.

G. W. Lapp†: The statement that 50 per cent excess voltage at normal frequency is a fairly safe limit applies to overexcitation of generators for ordinary plant conditions. If your usual voltage regulation was from 45 to 60,000 volts you had a 60,000 volt line instead of 45,000. On the leakage strip carrying the current, it appears from experiments we have made under spray that if you can supply the path of power with plenty of moisture, it remains good. In some cases higher values of wet flashover are obtained if the insulator is sprayed up under watersheds as well as down from the top. It is even observed on some bushings and some insulators that they show a higher wet flashover than dry flashover. This is a subject of current interest as it is being discovered insulators generally give higher dry flashover with higher humidity. If you apply a plentiful supply of water to a leakage path, it will absorb energy rapidly without blowing up. With good stream flow you can carry a lot of power away.

J. S. Murray‡: This Association is to be congratulated on the very fine papers presented on the insulator problem and the notable work and talent that insulator manufacturers have seen fit to give us today. While it is true nearly all voltages used in the steel mills are around 6,600 volts yet there are several installations of 22,000 volts, in mill property and subject to the well known conditions of dirt. In addition, higher voltages are planned, such as the installation of 65,000 volts mentioned by Mr. Farrington, all of which would indicate that we may need to consider the insulator problem from this standpoint later on.

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*Westinghouse Elec. & Mfg. Co.

†Lapp Insulator Co., Le Roy, N. Y.

‡Elec. Engr., Toronto Plant, Follansbee Brothers Co.

The theory advanced by the Lapp Insulator designs confirms our own practice, somewhat, in that it exposes more of the surface of the insulator to the rain and does not tend to pocket the dirt under the petticoat. We have had a few examples of this on the pin type insulators at Toronto.

We have an outdoor substation at one of our plants at 22,000 volts with 70,000 volt pin and strain insulators in a dirty, foggy atmosphere and I would like to hear from Mr. Fortescue if this insulator rating is proper on this voltage or if we may expect any damage at some weaker point from impulse voltages, for instance at transformer bushings which are insulated for 45,000 volts?

This matter seems to me to be a case of where we must be careful to use insulators of proper rating on the voltages to be handled, keeping in mind types that do not trap dirt to any great extent and then laying out a periodic schedule of cleaning, rather than going to higher ratings where we may endanger other more expensive apparatus on the system from impulse voltages.

It has certainly been a pleasure to hear the discussions of Mr. Lapp and Mr. Fortescue regarding insulator design fundamentals and particularly the theory of the ground wire and lightning discharge and their effect on transmission lines.

J. J. Torok*: There has been considerable discussion concerning insulator flashover as a means of protection to apparatus. Someone has suggested that if insulators which would stand flashovers could be made, the protection problem would be solved. I think we can do a little better than that. Something can be put on these insulators which will prevent the flashover from damaging them and yet this something else will flashover and take the surge off the line, thus protecting the power supply apparatus.

In going about this we used the information that we have obtained in the field as an indication of the upper limit of voltage appearing on a string of insulators. In order to determine anything definite, we had to go to the laboratory and reproduce the same conditions we had found on the line. This could be accomplished by applying a very rapidly rising surge. Since we could get as high as 3,000,000 volts, all conditions could be readily reproduced.

I wish to bring out some of the methods, whereby we can protect insulators from surges, in many cases even from direct strokes. In making a study of insulators, it is necessary to generate surges with the voltage remaining nearly constant for 100 microseconds which gives an impulse ratio of unity; that is, the surge flashover voltage is equal to the 60 cycle value. Steep waves are then applied, such that the insulators will break down on the front of the wave and thus produce a high impulse ratio. Instead of using a standard wave, we based our results on the rate of rise of voltage, which makes reproduction of the tests by other apparatus possible. The rising portion of the surge or wave front, we determine, not by calculation, but by actual measurements, which give the correct rate of rise at all portions of the wave. In carrying on the investigation we obtained a wave similar to that shown by Mr. Fortescue, (Curve 1). This curve shows clearly that as the time of voltage application is decreased, the breakdown potential rises. Then again it has been found that any voltage application, corresponding to any point above (a) on curve 1, will cause cascading of the insulators. This is a serious condition because the power arc always follows the path formed by the lightning discharge and cracks the insulator, rather than the surge itself. This has been shown many times in the laboratory, where insulators have been cascaded under the heaviest lightning discharges, and the worst effect has been an occasional chipping of the porcelain.

Mr. Vincent has demonstrated some arcing horns, which are much better than the old needle point type, since they will prevent cascading for short strings of insulators. On longer string of insulators, however, they will fail to protect against rapidly rising surges. He has started in the right direction but lacking time lag tests he has not carried the design far enough.

The arcing ring on exhibit here is another step in the right direction, but one which will possibly get the designers into difficulties of which they are not aware at present.

We have tested various forms of arcing rings. Many of them will prevent cascading under slowly rising surges, but will fail to protect under the steeper surges. Consequently we have carried out a systematic group of tests, which enables our designers to make rings that will protect under all conditions. These rings must also be so constructed that the power follow arc can travel all around the ring. This group of arcing ring tests gave much information on the area, the separation of the rings, the distance the ring should be from the insulator

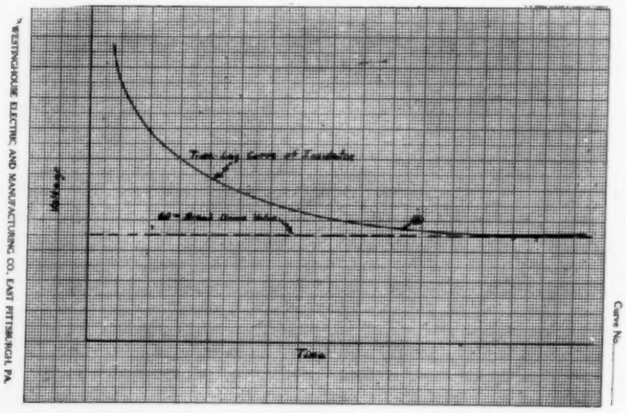

FIG. 1.

and the shape of the rings. Tabulating the results of these tests, we obtained curves which enable us to design rings for any given length of insulator strings. So successful were the tests that arcing rings constructed from interpolated values prevented insulators from cascading under any condition.

From a system of curves, similar to the one described above, we can protect all our insulators in a similar manner. This is quite an advantage as many power systems employ both suspension and pin type insulators. If a pin and suspension type with equal 60 cycle flashover values are tested under surge impulses, it will be found that the time lag

*Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

of the pin type is much greater, than that shown in Fig. 1, which is the time lag curve of a string of suspension units. Such time lag curves can also be applied to disconnect switches where a flashover may cause very serious trouble. By the use of time lag curves we can intelligently choose the type of insulator that should be installed at any point of a system to obtain adequate protection from lightning surges at that particular point.

There are various factors entering into the problem of design of insulators, arcing rings and arcing horns, which cannot be entered into here as it would require too much discussion and wearisome detail. However, an element that cannot be justly omitted has entered the field recently. This has already cleared up many mysterious happenings, and will undoubtedly be of great use in the future. The recent discovery of a method of stopping electrical discharges at any stage of their development has given much of the information necessary for correct designs. These stopped or "suppressed discharges" as they are called, show that the breakdown of air is not instantaneous but is brought about by conducting streamers traveling from one or both electrodes. By recording the formation of these streamers at various stages of their development, it is possible to determine the various paths which they may take. Then, by rearranging the designs, the streamers can be directed in any direction desired. By such processes arcing rings and arcing horns which will prevent cascading under the most severe line surges can be designed.

J. T. Littleton, Jr.*: The papers brought out very clearly that the loss of electrical insulation by dirt is of considerable importance. It is evident that this loss of insulation is affected to a certain extent by the design of the insulator and it is also a probability that the properties of the insulating surface will also be a factor. There is one point, however, which needs consideration. Under certain conditions it is probable that any insulator in the course of time will need to be cleaned but what the engineer is interested in is the ease of cleaning and how the cleaning affects the properties of the insulators. I should be interested in an insulator that is easily and thoroughly cleaned and which would not have its properties affected by such repeated cleanings.

There is another point which I do not feel I can pass over without discussion even though I believe that the majority of you understand the situation. The statement was made by one of your speakers that glass was not good for insulation on account of the fact that it was a vitreous material and consequently was full of internal strains and that these internal strains were known to be present because the material would not stand a thermal cycle test. This statement is obviously incorrect. Fused quartz is a vitreous material such as glass and it is well known has an extremely high resistance to sudden temperature changes. The resistance of a material to such changes depends upon the physical constants of the material such as thermal expansion coefficient, thermal conductivity, tensile strength, etc. The thermal resistance of a body in addition depends upon its dimensions as well as the physical properties of the material. A body one inch thick will stand considerably more of a heat shock than a body two inches thick of the same material and of the same identical structure.

Internal strains may not have anything whatever to do with the ability of a body to resist thermal cycle tests. An instant's consideration of the distribution of stress in a body strained in cooling will show that a strained piece of glass, strained in cooling may be more resistant to sudden heat shock than a perfectly annealed specimen. As the body cools from a plastic condition a certain portion of the inside tends to shrink away from the outside. This throws the outside surface layer under compression resisting this shrinkage action of the internal portion. If the body be then suddenly cooled when in such a strained condition the contraction of the external layer with respect to the internal portion of the body tends to throw this layer under tension but before there can be any tension the compression has to be first overcome. After overcoming the compression the tension must exceed the tensile strength of the material before breakage takes place. The initial compression caused by the strained condition acts as a counterbalancing force to the tension introduced by the sudden cooling and consequently the body is more resistant to sudden cooling.

It has been repeatedly mentioned tonight that insulators fail in service due to thermal cycle changes and that thermal cycle tests on insulators have been developed in order to select insulators which would not fail in service due to such changes. Of equal importance with the ability to resist thermal cycle changes in service is the ability of the insulator to avoid any such thermal cycle changes. If the insulator is not heated in service thermal cycle tests are no gauge of quality even though the material may be very resistant to such tests Experiments made by us and others show that a black body such as porcelain may be heated in sunlight up to a temperature approaching 100°C. A transparent body however is not heated by sunlight. When a body is broken by a thermal change a break is caused not by the temperature of the body but by the difference in temperature between certain portions of the body. Consequently a material which is not heated by the sun, in which no portion of the body is in the shadow of another portion, is at a uniform temperature throughout itself and can never have any but only very slight thermal stresses set up in it. Such a body can consequently be made in much heavier sections than another one which is locally heated and does have high thermal stresses introduced. Accordingly a thermal cycle test is only of benefit in testing a multi-part insulator as a test of assemblage stresses and for testing bodies which actually do become hot in sunlight. They are then of no benefit whatever in testing the service of a material which is in one piece and which is not heated in sunlight.

L. A. Lewen*: I want to take this opportunity to ask engineers if there is anything inherent in design of 66 pin type insulator which makes it a bad arc conductor? That applies in like manner to

*Chief Physical Laboratory, Corning Glass Co., Corning, N. Y.

*West Penn Power Company.

low type insulator. It seems to be an inherent feature of pin type insulators as they grow larger in size, they decrease in capacity. As that decrease in capacity takes place, electrostatic takes place and that is accompanied by tight wire strains. The dielectric stress where tie wire touches insulator is very high. Also the dielectric strain is high around the pin. So in a perfect it would be necessary to coat the insulator and that would have to be extended to a point underneath to a limited extent. If there is no one here who has actually done work on it, I would suggest Mr. Cox would answer the question.

J. H. Cox*: Mr. Fortescue has covered the ground on the protection of transmission lines against lightning, including ground wires and klydonograph information, rather thoroughly and I have only a few comments to add to his discussion. He has told you about the protection afforded by ground wires, and at the present time nearly all transmission engineers are strongly in favor of the use of ground wires on high voltage lines.

In connection with the protection afforded by ground wires it is well to remember that the reduction in the number of flashovers experienced is greater than the percentage reduction in voltages induced. This is illustrated in Fig. 1. If the number of surges of any voltage experienced on a line without ground wires, is plotted against voltage, the curve will be of the form of the upper curve in the figure. If then the horizontal line represents the flashover voltage of the line in question, then all surges above this horizontal line and below the curve will represent line flashovers. A similar curve can be drawn for the same line under the same atmospheric conditions, but equipped with ground wires, by reducing each abscissae by the percentage reduction accomplished. Such a curve would then be similar to the lower curve in the figure. It is obvious that the area representing flashover is now reduced by a much larger percentage than the percentage reduction in voltage. In fact, it is easy to see that on a high voltage line this area might almost disappear.

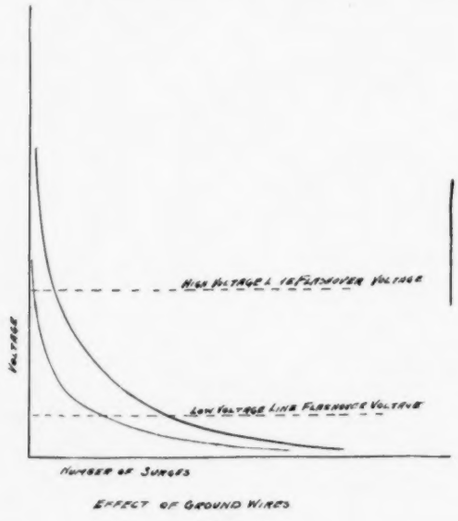

FIG. 1.

The curves of Fig. 1 might represent the surges encountered on any line of a given height in a given location, regardless of the operating voltage. Then for different values of insulation the horizontal line would be in different positions relative to the surge curves. It is evident that, for the lower values of insulation the flashover area, even after the reduction, might still be appreciable. The question arises; on lines of what voltages are ground wires desirable? It is seen that, for the lower voltage lines, even after the reduction in voltage of the surges, there might remain too many with flashover magnitude. In this case other means might be necessary to give satisfactory operation. However, on any line, ground wires will give a definite protection and would alleviate conditions encountered, and whether or not they would be economically justified depends upon the individual situation.

I have made some calculations on the influence of resistances, both ground wire and ground resistance, on the performance of ground wires. These calculations indicate that ground resistance has little influence on the performance of ground wires, if of any reasonable value. If the resistance is too high to permit the complete reduction at the first tower, the additional reduction will take place at subsequent towers until the ground wire reaches ground potential. From this point on, the ground resistance has no influence. However, if a surge causes flashover at all, this flashover will generally take place at the first tower from where the surge is initiated, and it is therefore important that the surge be reduced as much as possible at this point. Therefore, an effort should be made to provide ground resistance reasonably low, but a value less than about 100 ohms gives negligible effect upon the protection provided.

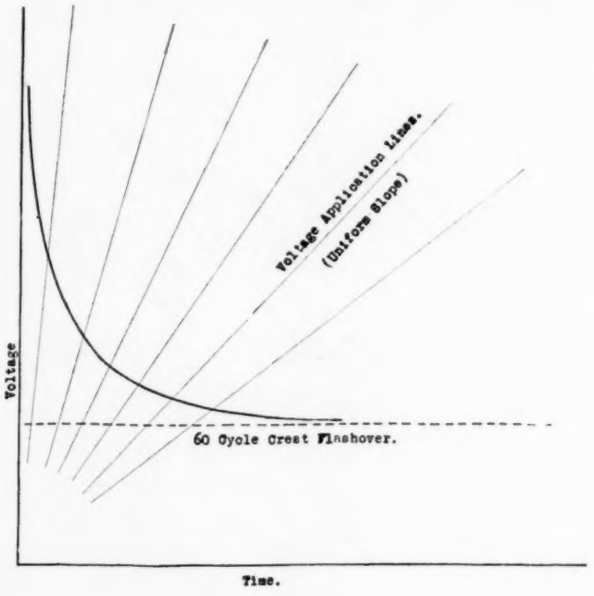

FIG. 2.

The series resistance of the ground wire itself has negligible influence if a conducting material is used. Even assuming a steel ground wire, and a resistance to surges equal to 100 times the d.c. resistance, the reduction in protection provided is

*Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

less than 1%. However, the resistance of a steel wire to an impulse is quite unknown and might be many times greater than 100 times the d.c. resistance. Therefore, it is desirable that a conducting material be used. Fortunately the conducting materials are also weather-resisting materials and, as brought out in Mr. Fortescue's discussion, the quality of installation of the ground wire should be equal to that of the rest of the line. A thin outer coating of conducting material is entirely satisfactory, and is cheaper than a conductor of the ordinary line conductor type.

A considerable amount of protection for station apparatus is provided by any capacities connected to the line at the terminal. The condenser type bushing provides an admirable capacity of this type. When a travelling wave reaches the open end of the line, it reflects and impresses double the incoming voltage. A transformer connected to the end of a line presents essentially the same condition to a brief impulse as an open line. If the line is shorted at the end, the voltage reflects with reverse sign and impresses zero voltage at that point. In the first instant a condenser presents the same effect as a short circuit. With the advance of time, the condenser becomes charged and if the wave is of long duration the potential reaches, finally, the same value as it would on an open end line. Therefore, small capacities only provide protection for steep short duration surges. Taking a typical example of a 220 kv. line terminating in three condenser type bushings per phase, that is, two in a circuit breaker and one in a transformer, a million volt surge with a front of 0.1 microsecond, instead of reaching two million volts would be limited to 200,000 volts, provided it is chopped by an insulator flashover and the tail of the wave removed. With a one microsecond wave the reduction is less, and is only about one-half. For a five microsecond wave, or a steep front wave with a duration of five microseconds, the protection is negligible.

In Mr. Hawley's paper the statement was made that, by virtue of the impulse ratio of insulators, a line would withstand a surge ten times normal without flashing over. As brought out by Mr. Fortescue, if a steep front surge greatly above the 60 cycle crest flashover is impressed on an insulator, the voltage will reach considerably above the 60 cycle crest flashover value before the flashover takes place. However, if a surge, with a duration as produced by lightning, and only slightly above the 60 cycle crest flashover is impressed on an insulator, the insulator will still flashover. In other words, for a full length surge as produced by lightning, the impulse ratio of line insulation is one. This checks with the results of our klydonograph investigations. Records were obtained of voltages ten or more times normal, but in each case such records were accompanied by a line flashover. In no case was a record obtained more than about seven times normal, or the 60 cycle crest flashover value, when a flashover did not occur. In other words, the insulation would not withstand lightning surges above the 60 cycle crest flashover value.

D. M. Petty*: We built our transmission lines carrying 6600 volts, ten or fifteen years ago. We started with insulators having a nominal rating of 15,000 volts and had some trouble. These were replaced with insulators with normal rating of 35,000 volts and the trouble has been eliminated. The thing that had me worried until the last speaker read his paper was that we were insulating our lines for voltages somewhat above their transmitting voltages, and therefore surges having no place to spill over would carry into our 6600 volt motors and generators and cause insulation failures.

Lightning arrester has been suggested as the answer and we are going along with that idea. We spent a good deal of money also on putting ground wires over our 6600 volt apparatus, and I gather we might have saved all that money.

D. M. Petty: What is it on 6600 volts?

J. H. Cox: I would have to calculate that.

D. M. Petty: What do you reduce strain on insulators in volts?

J. H. Cox: The voltage reduction varies according to the arrangement and the initial induced voltage.

D. M. Petty: That is 35,000 volts is some fixed value of reduction; your ground wire has not done any practical good?

A. C. Cummins*: Steel mill electrical engineers as a class have had little operating experience with power transmission at high voltages. The average steel plant uses either 2200 or 6600 volts for transmission purposes and there are only a few installations where 22,000 and 44,000 volts are used. Where higher voltages are used dirt has become such a factor in the vicinity of Blast Furnaces that in foggy or misty weather it seems to be almost universal to find that visible creeping is apparent even in daylight. The steel mill engineer is very anxious to learn from public utility operating men whether visible leakage permanently damages insulators and bushings, and if a complete failure is to be anticipated after a short period of such leakages. All operating men realize that when leakage over insulators becomes of such magnitude as to become visible that insulators should be cleaned at the earliest opportunity. The question that is now bothering a few steel mill operators is whether this cleaning should be done immediately, even at the expense of affecting production, or whether it is safe to delay such cleaning for several days or even weeks until a power outage can be conveniently arranged.

Mr. Lewis' rules for induced lightning voltages seems hard to apply to steel mill conditions. One tower that I know if in the vicinity of a steel plant is approximately 250 feet high to the bottom cross arm. Though it is equipped with ground wires it would appear that induced lightning voltages of at least 15 million can be anticipated. The problem of designing insulators for such conditions is beyond the present stage of the art. Perhaps the constructors of this line have been fortunate in securing a location not frequently exposed to lightning voltages. Otherwise a very great number of flashovers will occur during the lightning season. I would like to

*Elec. Supt., Bethlehem Steel Co., Bethlehem, Pa.

*Elec. Supt., Carnegie Steel Co., Duquesne, Pa.

(Continued on Page 389)

Analysis of Power Consumption Test 16" Roughing Stand Timken Steel Mill

*Timken Bearings vs Plain Bearings on Roll Necks**

By F. WALDORF†

This article consists of an abstract taken from a report compiled by the Timken Roller Bearing Co. June 15, 1926, and a discussion presented before the A. I. & S. E. E. at their 24th annual convention June 28th, 1928.

THE benefits to be derived from the use of roller bearings in rolling mills have long been the subject of many discussions.

So well are they known, that, where the anti-friction industry was once the aggressor in the field, it already finds itself working overtime trying to keep abreast of the demands imposed upon it by the steel industry.

These demands are exceedingly numerous and extremely varied, and, in some instances, so difficult of meeting, as to cause the bearing makers no small concern.

In fact, one of the engineers of a well known steel company has several times expressed it as his conviction that the demand for anti-friction bearings for rolling mills, as yet, exceeds the art of producing them. The more one ponders over that statement, the more he comes to the belief that there is sufficient truth in it to justify the roller bearing manufacturer's looking well to his equipment and bringing it up to the point it must eventually reach if full service is to be rendered to the trade.

The benefits to be expected from the use of roller bearings in mills are four-fold. They have, to date, always been classified as Power Savings, Reduction in Maintenance, the practicable elimination of Repair Costs, and, the continuity of operation of the mills with the attending increase in both quality and production of the material rolled.

The one benefit, however, that is of the greatest importance, is Savings in Power. It is the one question that is brought up with increasing regularity and persistency, and while the bearing manufacturer today is only a bearing producer, it appears that he may shortly be called upon to assume the role of consultant, who, because of the close relations he has with both mill builders and operators, would be able to fix upon the sizes of bearings that could be safely recommended for the service any mill is to perform.

Before such a favorable condition could be brought about, much development work would have to be done. Mills of every type would have to be tested out for every condition of rolling.

The action of steels of different analyses and temperatures, in mills of various sizes, would have to be observed. Data would have to be accumulated, and later compiled in such form that would permit of its use with confidence and with safety.

The members of the Association have long been cognizant of the fact that the motor builders have been collecting data for years on the power requirements for driving rolling mills. You should therefore readily agree that it would be years before any anti-friction bearing manufacturer could be in position to assume the responsibility the steel industry already desires to impose upon him.

It is indeed remarkable what definite progress has thus far been made in the application of anti-friction bearings to roll necks. It is particularly so because the mill operator was almost without any knowledge of the actual pressures that are required to roll steel of various kinds. The bearing manufacturers have therefore been obliged to run a number of costly tests to determine these pressures before proper bearings could be designed.

It is our belief that the steel producer should determine the loads imposed upon his mills for different classes of rolling. This knowledge is vital to him regardless of whether he is now using, or plans to use, bearings of any kind.

If the industry took it upon itself to do this, it would be giving anti-friction bearings the same break they now receive from some fifty other large industries which now use them. The steel industry is today the only industry that does not tell the bearing builder what loads they desire to handle.

In many mills where anti-frictions are now being used, we find very little information as to what power savings is being realized.

At the outset, you accepted, without reservation, our statement that from 30% to 40% savings in power can be effected through the use of roller bearings in mills. These figures were quoted by us only after we had spent months in making observations and collecting data on our 16" 3-High Bar Mill, which, by the way, consists of only one stand.

An analysis of the data which formed the basis upon which our statement was issued will presently be made, but in the end you will note that our results give information only on rolling several sizes of squares to two sizes of ovals.

Before we can, with safety, assume the responsibility of fixing the size of a bearing to be used in a mill, it will be necessary that tests of endless description be made.

There is only one laboratory in which such tests can be made and that is the existing steel mills in

*Presented before the Association of Iron & Steel Electrical Engineers, June 28, 1928, at Chicago, Ill.

†District Mgr., Timken Roller Bearing Co., Steel Mill Division.

the country. The Timken Steel Plant rolls, in the main, only such products as it requires for the manufacture of roller bearings. Our facilities for making tests are therefore limited to squares, rounds and some seamless tubing. All other types of tests would have to be made in the steel mills in the country, and time alone will tell to what extent they would co-operate with us in the quest we all must make before the question of roller bearings for all types of mills can be successfully solved.

Under date of June 15, 1926 we published a report of the test we ran on our 16" 3-H Mill.*

Two hundred and seventy-nine billets, in all, were rolled during the test, but because of the diversity of steel and analyses handled, our report gives comparative data on only 160 of the total number of billets rolled. The report shows reproductions of twelve wattmeter charts that were taken at random. Six of these charts cover the rolling of steel on plain bearings and the remainder show the results while Timkens were used.

On pages 22 to 27 inclusive of this report, we show tables giving the logs of each individual billet rolled. The steel rolled, the size of billet, the total reduction taken, and the final section rolled are given at the tops of the tables. The type of bearing is also given.

Each billet, in each test, is numbered and the complete rolling data, such as mill speed, temperature of the steel, and the maximum K.W. used is also given. In the last three columns we give the power consumption in K.W. hrs. per foot of billet, for total load, friction load, and net rolling load.

In the analyses of the charts that will follow, the K.W. hrs. per foot of billet merely represents the total K.W. hrs. used while the billet was rolled

*Reprints may be had.

FIGS. 8 AND 9—TYPICAL WATTMETER CURVES

3"x3" Billets—2½"x1" Oval—Nickel Moly. Steel

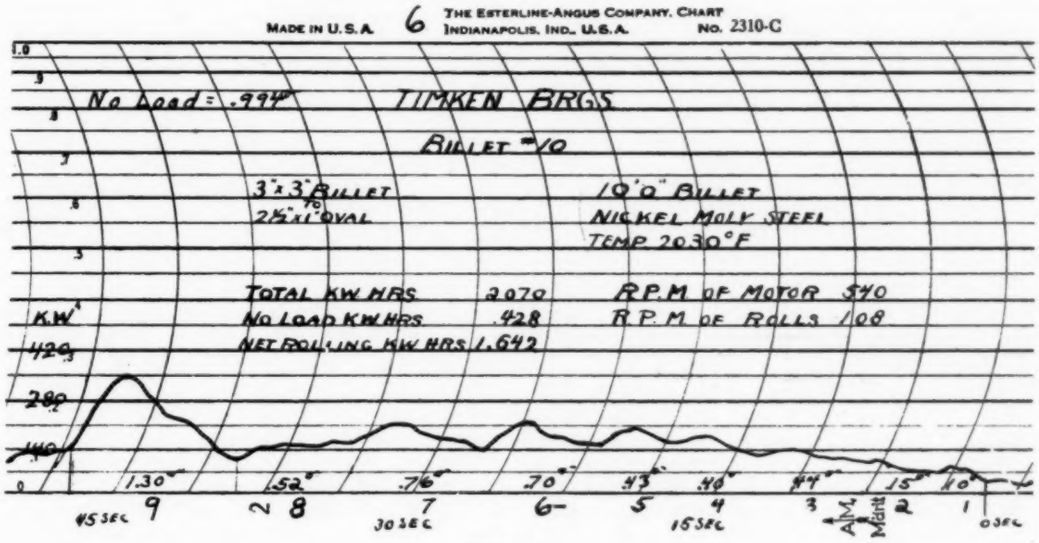

FIG. 8.

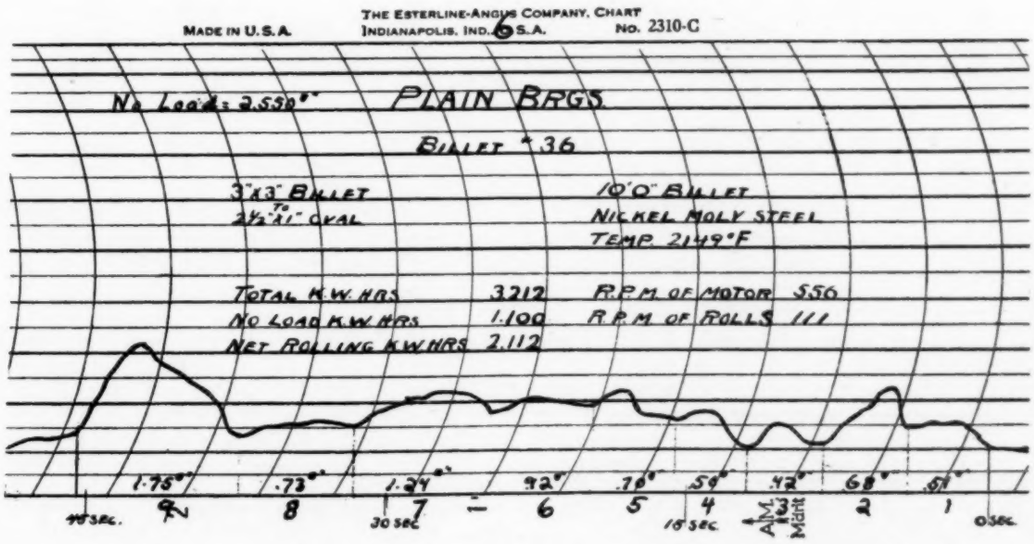

FIG. 9.

FIGS. 10 AND 11—TYPICAL WATTMETER CURVES
3"x3" Billet to 2½"x1" Oval—1.25 Nickel Steel

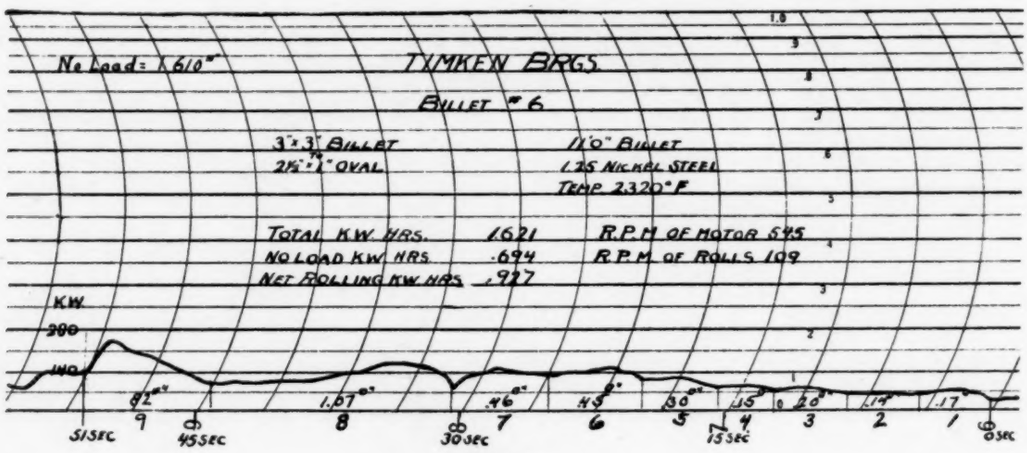

FIG. 10.

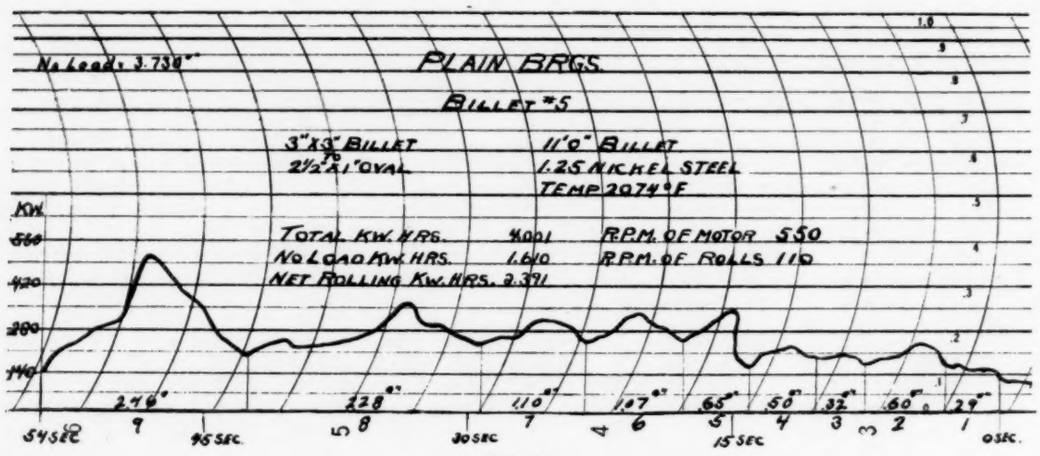

FIG. 11.

FIGS. 12 AND 13—TYPICAL WATTMETER CURVES
2½"x2½" Billet to 2½"x1" Oval—3.5 Nickel Steel

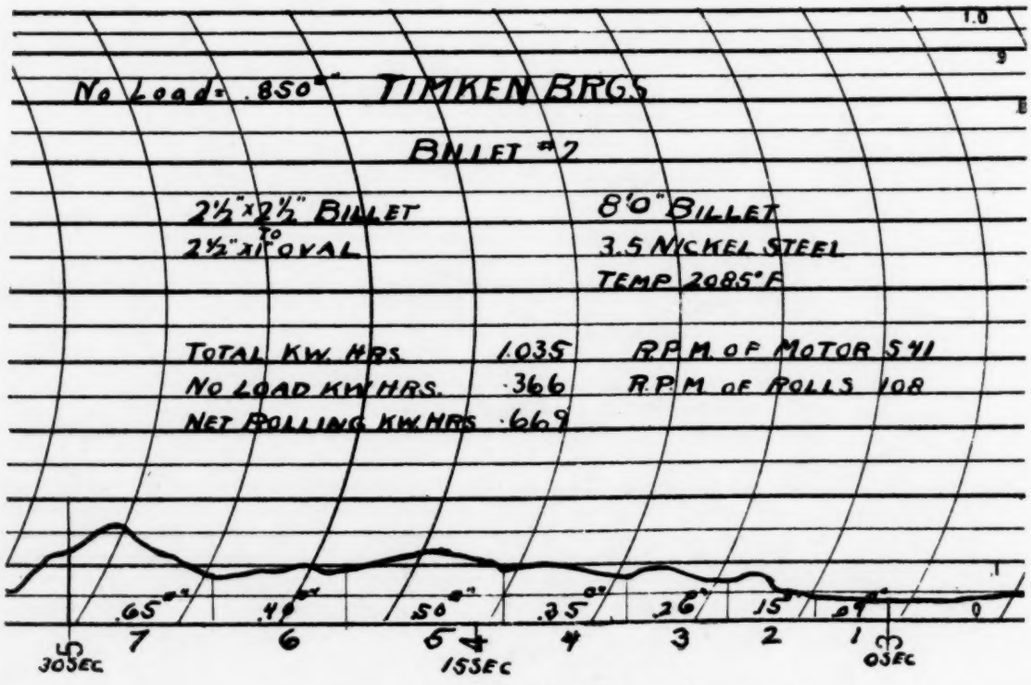

FIG. 12.

divided by the length in feet of the billet as it came from the furnace.

The average results published on pages 11, 13, 15, 17, 19 and 21 are those given at the bottom of the tables appearing on pages 22 to 27 inclusive, but these averages cannot be applied to the twelve charts shown in the report when the analysis of any one chart is made.

The rolling characteristics for the individual billet covered by the chart in question must be taken from the tables on pages 22 to 27 inclusive and analyzed individually.

In other words Figure 8 on page 10 covers billet number 10 in the log of tests on page 22; Figure 9 on page 10 covers billet number 40 in log of tests on page 23. The billet number 36 given in Figure 9 is no doubt correct and apparently the characteristics for this billet was listed in error under number 40 on page 23.

One of the papers read on Tuesday of this week gave the power consumption in terms of K.W. hrs./Gr. T/N and H.P. Sec./1 cu. in. displ./N.

Since our tables publish the power consumption in terms of K.W. hrs. per foot of billet rolled, it

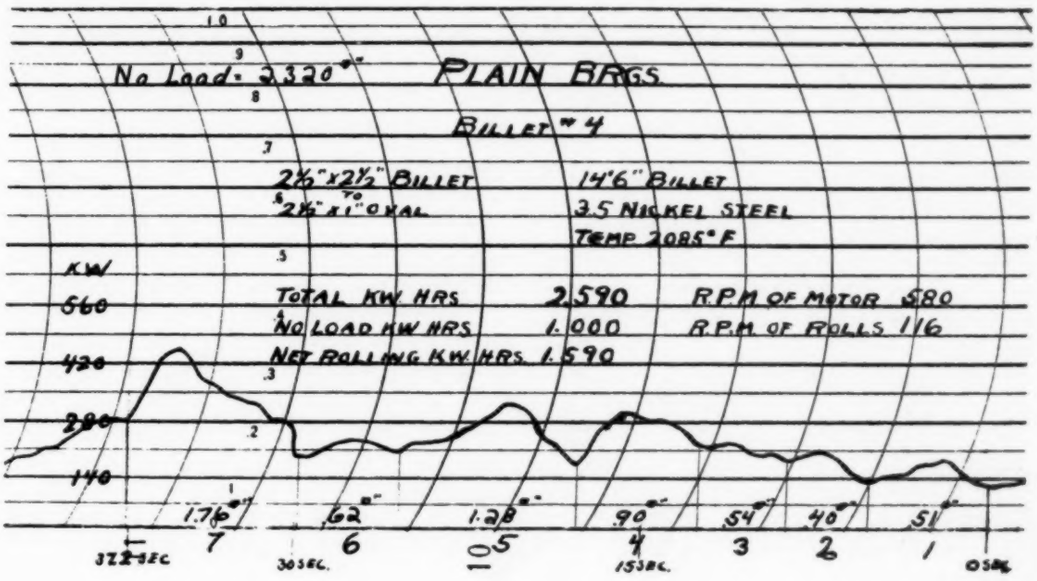

FIG. 13.

FIGS. 14 AND 15—TYPICAL WATTMETER CURVES
2½"x2½" Billet to 2½"x1" Oval—1.25 Nickel Steel

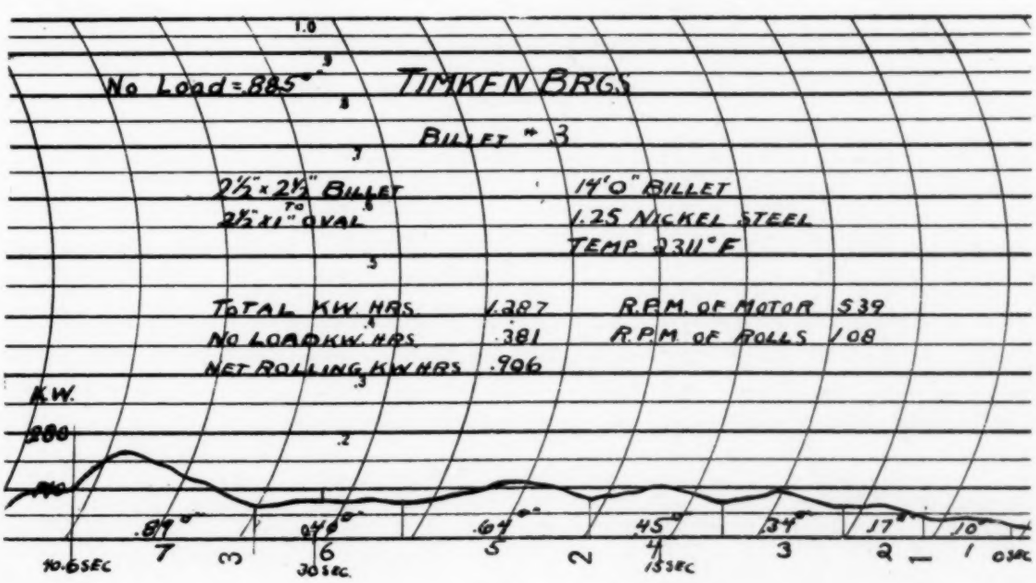

FIG. 14.

will be in order to convert this term into terms that are used by the industry at large.

The figures that are shown herewith are reproductions of figures 8 to 19 inclusive, pages 10 to 20, as published in our 16" Mill test report; and for ready identification are given the same numbers in this analysis.

As each pair of charts is analysed, reference should be made to Fig. 1 which is a tabulation of the results of each analysis made, and finally gives the average power savings obtained from the six comparisons of the plain and Timken charts shown in this report.

The method of converting the information on the chart to the terms used by the industry is as follows:

$$\frac{2240 \times \text{K.W. hrs.}}{W} = \text{K.W. hrs./Grs. T/N}$$

K.W. hrs. = Total K.W. hrs. used while rolling the billet covered by the chart.

W = Weight of that billet in pounds.

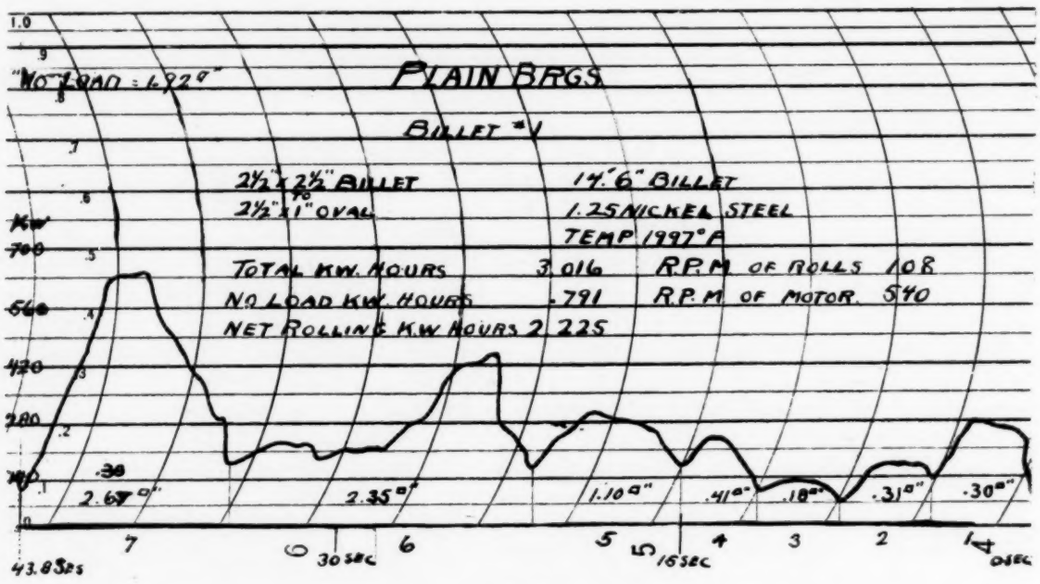

FIG. 15.

FIGS 16 AND 17—TYPICAL WATTMETER CURVES
2"x2" Billet to 1¾"x⅝" Oval—3.5 Nickel Steel

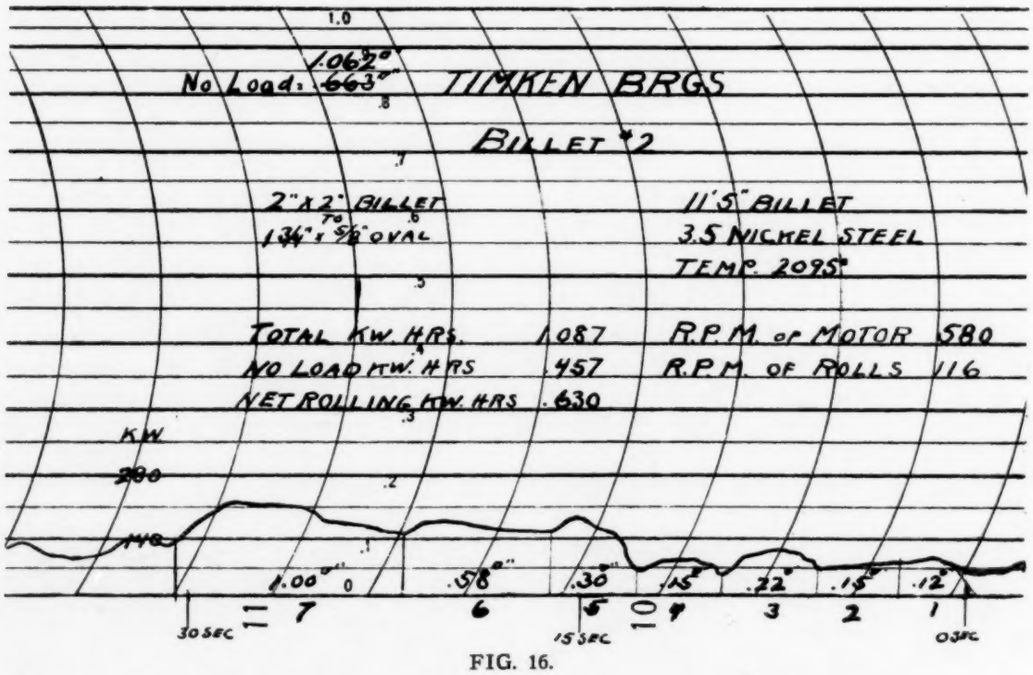

FIG. 16.

2240 = Number of pounds in one gross ton.

and

$$\frac{2{,}653{,}200 \times \text{K.W. hrs.}}{550 \times R \times L} = \text{H.P. sec./1 cu. in. displ./N}$$

K.W. hrs. = Total K.W. hrs. used while rolling the billet covered by chart.

R = The total reduction in square inches.

L = Length of billet before rolling, in inches.

2,653,200 = Number of ft. pounds in one K.W. hr.

550 = Number of foot pounds in one H.P. sec.

An inspection of Fig. 1 showing the tabulation for the six pairs of charts will show that the percent

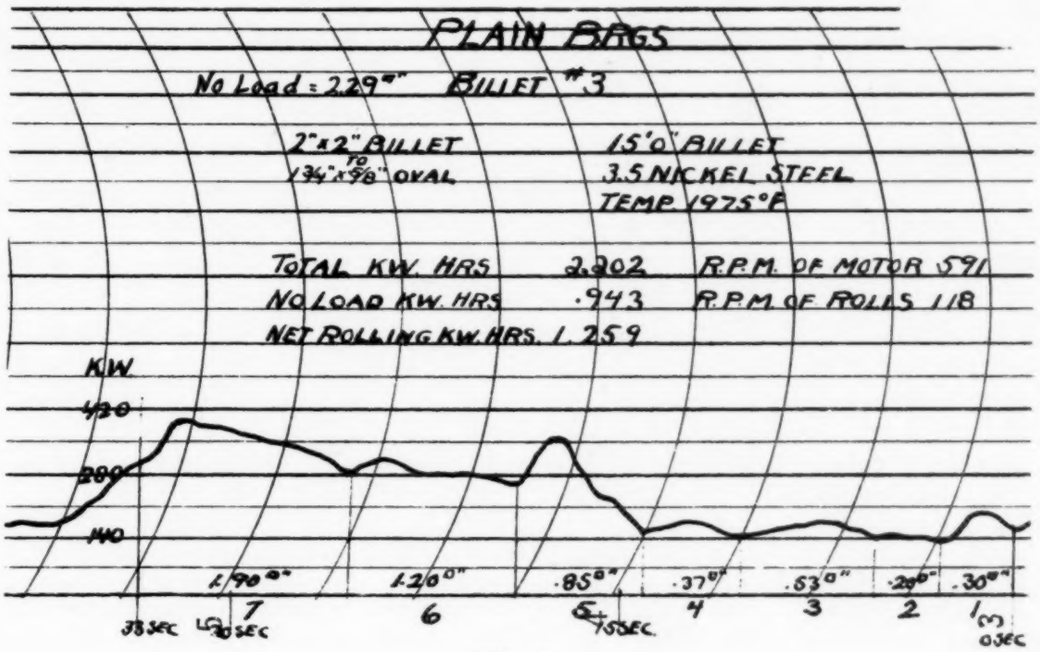

FIG. 17.

FIGS. 18 AND 19—TYPICAL WATTMETER CURVES
1⅞"x1⅞" Billet to 1¾"x⅝" Oval—Nickel Moly. Steel

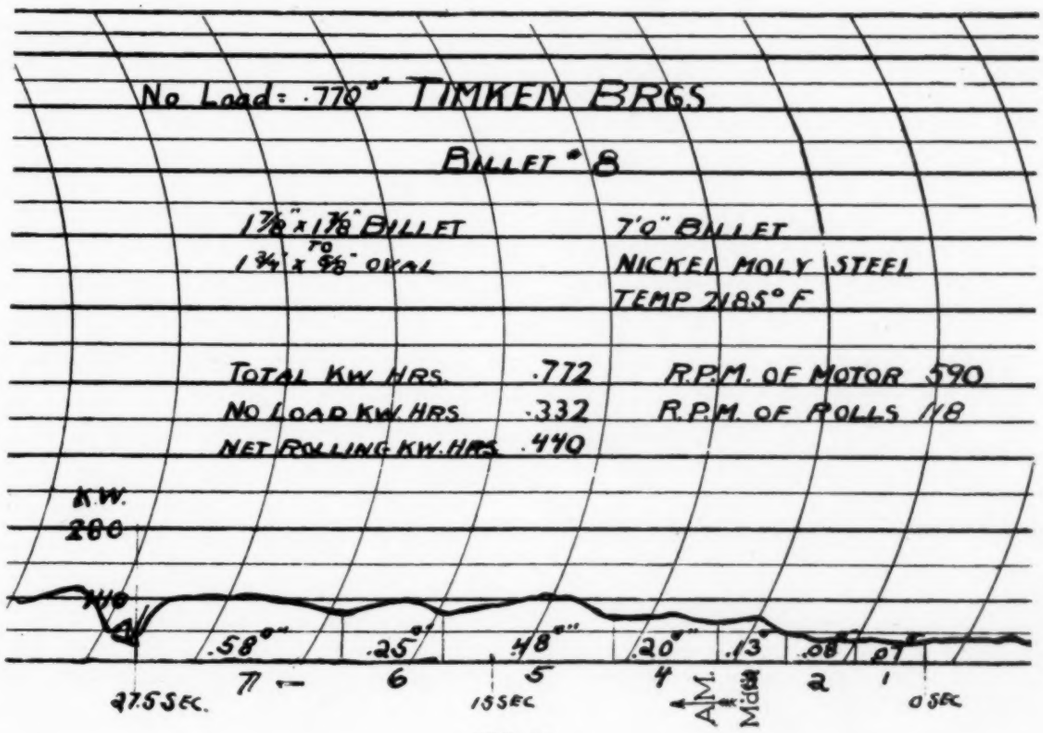

FIG. 18.

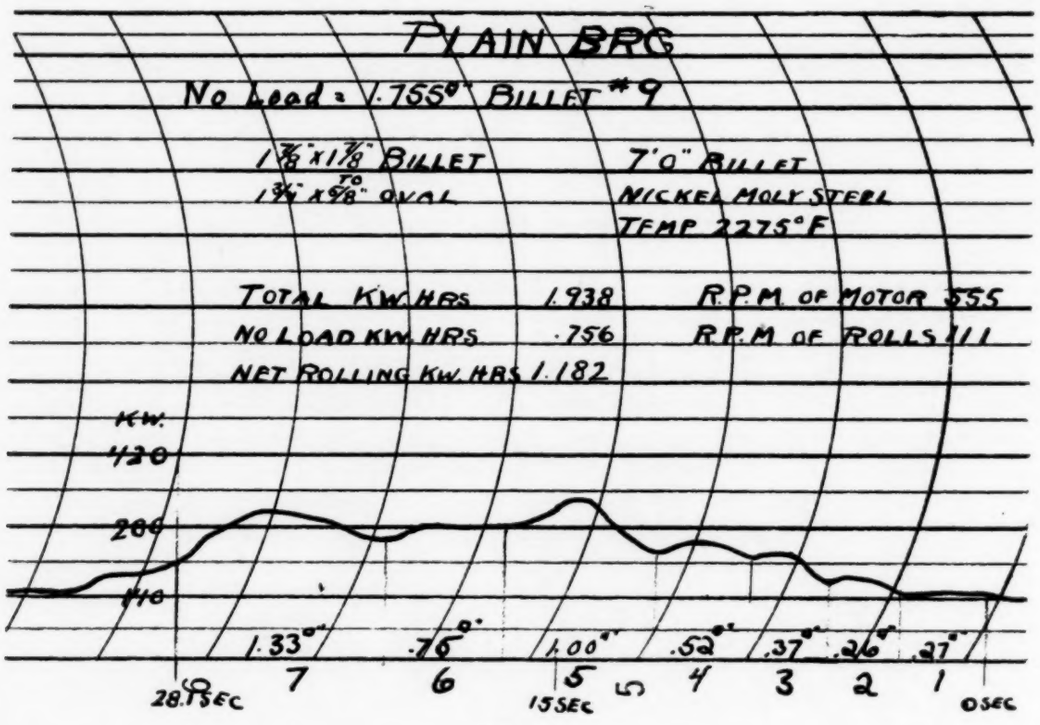

FIG. 19.

Size of Billet	Section Rolled	Steel	No Passes	Lgth. Billet	Wgt. Billet	Rolling Cyc. Sec.	Temp. Billet	R. P. M. Mill	Reduction □"	Displmt. Cu. in.	K. W. H./Gr. Tn. Plain	K. W. H./Gr. Tn. Timkens	Difference	% Savings	H. P. Sec./Cu. In. Plain	H. P. Sec./Cu. In. Timkens	Difference	% Savings	Fig.
3"x3	2½x1	Ni Mo	9	10'–0"	305	46	2149	111	7.02	842	23.55		8.5	36	18.4		6.5	36	9
	Oval			10'–0"	305	46	2030	108				15.18				11.86			8
3"x3	2½x1	1.25 Ni	9	11'–0"	336	54	2074	110	7.02	927	26.66		15.9	59.5	20.8		12.2	59.5	11
	Oval			11'–0"	336	51	2320	109				10.8				8.56			10
2½x2½	2½x1	3.5 Ni	7	14'–6"	307	37	2085	116	4.27	743	18.92		5.24	27.7	16.8		4.6	27.4	13
	Oval			8'–0"	170	30	2085	108		410		13.68				12.2			12
2½x2½	2½x1	1.25 Ni	7	14'–6"	307	44	1997	108	4.27	743	22.02		12.3	56	19.55		10.9	55.5	15
	Oval			14'–0"	297	41	2311	108		717		9.72				8.7			14
2x2	1¾x1⅝	3.5 Ni	7	15'–0"	197	33	1975	118	3.00	540	25.03		8.8	35	19.65		6.9	35	17
	Oval			11'–5"	150	31	2095	116		411		16.26				12.77			16
1⅞x1⅞	1¾x1⅝	Ni Mo	7	7'–0"	80	28	2275	111	2.52	212	53.94		32.5	60.5	44.2		26.7	60.5	19
	Oval			7'–0"	80	28	2185	118				21.48				17.5			18

45.7 ave.

TABLE NO. 1.

TABLE NO. 2.

Length of Billet	Weight of Billet	Temperature of Billet	R. P. M. of Mill	Displacement In Cubic Inches	K. W. H./Gr. Ton Plain	K. W. H./Gr. Ton Timkens	Difference	% Savings	H. P. Sec./Cu. In. Plain	H. P. Sec./Cu. In. Timkens	Difference	% Savings	Reference
10′–0″	305	2149	111.2	842	23.55		12	51	18.4		9.35	51	Fig. 9
9′–0″	275	2149	96	758		11.56				9.05			Billet 22
10′–0″	305	2149	111.2	842	23.55		5.7	24.2	18.4		4.48	24.4	Fig. 9
9′–6″	290	2145	112	800		17.85				13.92			Billet 27
10′–0″	305	2030	108	842		15.18	6.22	29.1		11.86	4.84	29	Fig. 8
9′–8″	295	2030	107.4	814	21.4				16.7				Billet 19
10′–0″	305	2030	108	842		15.18	4.92	24.5		11.86	3.84	24.5	Fig. 8
9′–7″	293	2030	107.4	807	20.1				15.7				Billet 23

savings are not exactly correct except in the case of the third comparison. You will note that the temperatures are not the same except for that case.

That all of the other percents would change somewhat if the temperatures were the same is quite apparent, although the corrections would be slight. See Fig. 2.

A final reference to Fig. 1 will show that the overall savings for the six comparisons made amounts to 45.7%. If the corrections could be made for billets of the same temperatures it is probably more than likely that the overall savings would be at least 40%.

Returning to Fig. 2 billet No. 22 on page 22 of the report had a temperature of 2149°. This billet was 9 feet long and was rolled on Timken Bearings. The total K.W. hrs. used was 1.41 and which when converted showed 11.56 K.W. hrs. per Gr. Ton per N, and 9.05 H.P. sec. per C.I. displ. Comparing these values with the 23.55 and 18.4 shown for plain bearing rolling we get a saving of 51% in each case.

Billet No. 27 shown in Fig. 2 had a temperature of 2145° and was 9′ 6″ long. It was also rolled on Timkens. The total K.W. hrs. used was 2.31 making the K.W. hrs. per Gr. Ton 17.85 and the H.P. sec. per C.I. displ. 13.92. On comparing these values with those for the plain bearing rolling we get 24.4% saving.

Billet No. 19 in Fig. 2 had a temperature of 2030°F. It was 9′ 8″ long and was rolled on plain bearings. The power used to roll it was 2.81 K.W. hrs. giving us 21.4 K.W. hrs./Gr. T/N, and 16.7 H.P. sec./cu. in./displ.

Comparing these with the 15.18 and 11.86 shown for Timken bearing rolling we get a savings of 29%.

Again billet No. 23 in Fig. 2, also had a temperature of 2030°F. It was 9′ 7″ long and was rolled on plain bearings. The power used was 2.62 K.W. hrs. for this billet giving us 20.1 K.W. hrs./Gr. T/N, and 15.7 H.P. sec./cu. in./displ.

Comparing them with the values for the Timken rolled billet of the same temperature we get 24.5% savings.

36	273.9	237.9	237.9	237.9
59.5	36.0	24.4	29.0	24.5
27.4	237.9	6 262.3	6 266.9	6 262.4
55.5	51.0	43.7%	44.8%	43.7%
35	6 288.9			
60.5	48.1%			
6 273.9				
45.7				

If we now correct the overall savings shown by the six comparisons to cover the rolling of billets in comparison in Fig. 1 at the same temperatures we get 48.1, 43.7 and 44.8% savings. These are all above the 40% I just mentioned.

It so happened that at the time your author prepared the paper he read before the Association at Pittsburgh last June, he had in his possession the power consumption for each pass shown on charts, Figures 8 and 9.

With the limited time at his command he has prepared the rough analysis of each pass shown in Fig. 3 which indicates the results obtained.

You will note that the K.W. hrs. used per pass is given, the reductions taken per pass, and the H.P. sec./cu. in./N are also given. The third from the last column gives the percent of plain bearing power used by the Timken equipped mill, and the overall savings for the bar is given as 36.8% as against the 36% shown in Fig. 1.

You will also note that pass No. 8 was only a return pass. If it had been possible to finish the oval in eight passes, thereby eliminating the return pass, the actual K.W. hrs. would have totaled up 2.898 and 1.846 for plain and Timkens respectively, and the percent saving would have been 36.2% against 36.8% shown before.

However, as the mill was using power while returning the bar, the cost of same was charged to the rolling operation.

TABLE NO. 3.

No. of Pass.	Dimensions of Pass.	Reduction in □"	Length in Feet Before Pass.	Elongation†	Time of Pass, in Seconds	Cubic Inches Displ'd. This Pass.	K. W. H. Used By Pass.		Considering Entire Unit				% of Plain Bearing Power Used by Timken Equipped Mill	Considering Mill Alone		
									K. W. H./Gr. Ton This Pass.		H.P. Sec./Cu. In. Displ. This Pass. Lgt. From Col. 4.			Net Rolling H. P. On Basis of Max. K. W. Input During This Pass.		
							Bearings		Bearings		Bearings			Bearings		
							Plain	Timken	Plain	Timken	Plain	Timken		Plain		Timken
1	3"x2 7/16" Flat	1.70	10.0	1.23	4.2	204	.220	.078	1.61	.57	5.2	1.84	35.3	102.5	30	Approx.
2	2½"x2½" Edge	1.08	12.3	1.17	4.4	160	.293	.121	2.15	.89	8.9	3.68	41.2	234.0	75	Approx.
3	2 7/16" Diamond	.29	14.5	1.05	3.9	50	.181	.142	1.33	1.04	17.4	13.65	78.5	102.5		90.0
4	2 3/16" Diamond	1.11	15.2	1.23	3.8	202	.216	.164	1.58	1.20	5.2	3.95	76.0	146.0		141.0
5	1 31/32" Diamond	.87	18.7	1.22	4.3	195	.302	.203	2.21	1.49	7.5	5.05	67.3	215.0		166.0
6	1 25/32" Diamond	.65	22.8	1.20	5.5	178	.396	.250	2.91	1.83	10.7	6.75	63.0	203.0		191.0
7	1⅝" Diamond	.67	27.3	1.26	5.5	219	.535	.328	3.92	2.41	11.8	7.25	61.3	215.0		179.0
8	Return only	.....	34.4	.....	6.0	.....	.314	.224	2.30	1.64	—	—	71.4	121.5		102.0
9	2½"x1" Oval	.65	34.4	1.33	8.4	268	.755	.560	5.54	4.11	13.5	10.00	74.3	402.0		354.0
For total elongation		7.02	10.0	4.58	46.0	842	3.212	2.070	23.55	15.18	18.4	11.86	63.2	Average		
							2.898*	1.846*			16.55*	10.55*	36.8	Savings		
													100.0			

*Values if #8 pass could have been omitted.

†Assuming compacting of steel does not affect elongation.

If a similar correction were made for H.P. sec./cu. in. these items would be 16.55 and 10.55 against 18.4 and 11.86 for plain and Timkens respectively. The H.P. sec. values would be lower but the savings would be the same.

The K.W. hrs. used for pass 8 were for overcoming mill friction load mainly. That this is true can be seen from an inspection of the friction load charts shown in Figs. 6 and 7.

Figure 7 shows the no load wattmeter curve for plain bearings and you will observe that the line hovers somewhere around 110 K.W., and that for Timken Bearings around 70 K.W. See Fig. 6. In Figs. 8 and 9 the lines for pass No. 8 hover around 210 K.W. and 140 K.W. thereby showing that while no reduction was being made in the steel, the mill used some power while dragging the bar along the floor plates in front and back of the mill.

The formulae used when the H.P. sec. were calculated for the individual passes covered by Figs. 8 and 9 were as follows:

K.W. hrs. for the pass x 1.34 = H.P. hrs.

H.P. hrs. x 3600 = H.P. sec. for the pass.

$$\frac{\text{H.P. sec.}}{R \times L} = \text{H.P. sec./cu. in. displ./during the pass.}$$

K.W. hrs. = For the pass in question.

R = Reduction in sq. in., made during the pass.

L = Length of billet before the pass in inches.

TYPICAL WATTMETER CURVES

Friction Load

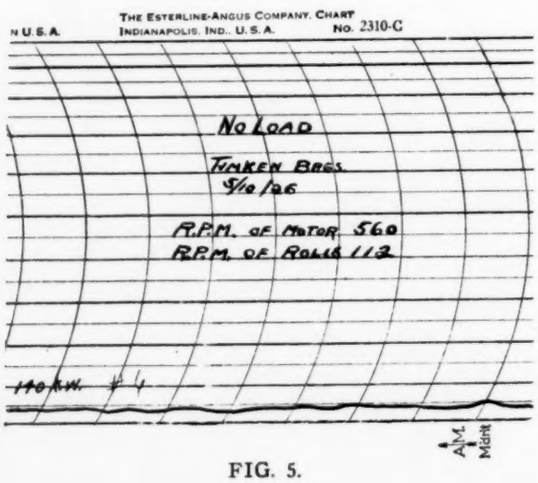

FIG. 5.

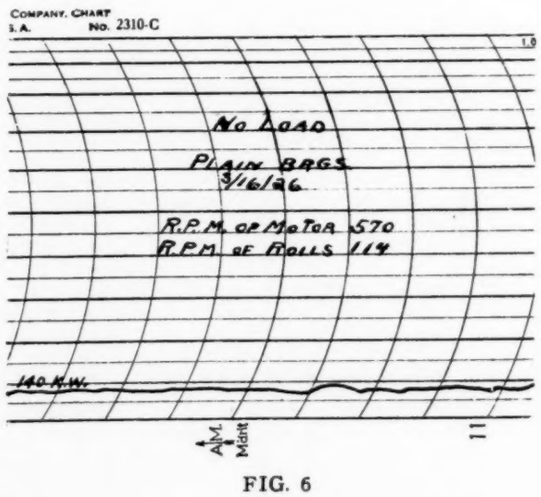

FIG. 6

The last formulae can be simplified somewhat if the length of the billet before the pass is taken in feet thus:

$$\frac{\text{K.W. hrs.} \times 1.34 \times 3600}{R \times L \times 12}$$ and by cancellation this becomes

$$\frac{402 \text{ K.W. hrs.}}{R \times L} = \text{H.P. sec./cu. in. displ./during the pass.}$$

L in this case being taken in feet.

In conclusion it should be said that the primary object of this paper is to give the industry assurance that the power savings to be gained through the use of anti-frictions can be assumed to approach 30%.

A check on power savings was made in a 10" 2-H rod mill which was an individually driven unit.

I do not have the exact data here on what oval was rolled, but the rod delivered was .612"O.

The power required to drive the mill while rolling on plain bearings was 170 H.P. The power required to drive the mill empty was 95 H.P. This left 75 H.P. for the actual rolling.

When Timkens were put on the roll necks alone, the power to drive the unit while rolling was 95 H.P. and this dropped to 20 H.P. when the mill was empty. This again left 75 H.P. for the actual rolling.

If you take the difference between 170 H.P. and 95 H.P. you get a savings of 75 H.P. or 44%.

In a Bliss cluster mill installation where up to 18" wide cold strip is rolled, a saving of 60% has been shown by the use of roller bearings. The comparison was of course made with two high mills as used at first.

In another plant where four high mills were installed for cold rolling wide strip, it was estimated that 350 H.P. motors would have to be used. On our advice 30% was cut off this size, and 250 H.P. motors were installed.

To date the maximum power required has not exceeded 180 H.P. Up to 38½" wide alloy sheets have been rolled at 13.1% reduction, the sheets being brought down from .114" to .099".

In some preliminary analysis your speaker recently made of a six stand 2-H continuous skelp mill the ranges were as follows:

13% in the first stand to 39% in the sixth, with an average of 26.8.

21.6% in the first stand to 40.6% in the sixth, with an average of 31.1.

19.0% in the first stand to 39.6% in the sixth, with an average of 29.6.

12.3% in the first stand to 36.0% in the fifth, with an average of 25.4.

From the above it appears that where loads are light and the speeds low the savings will not be so great as when loads are heavy and the speeds are high.

All of the foregoing savings were calculated from assumed rolling loads and co-efficients of friction.

Finally, your attention should be invited to one fact that is of greater importance to the bearing manufacturer than is the question of power savings. I refer to the problem of accurately knowing what loads anti-friction bearings must be prepared to take.

Sixty-nine pressure tests we have so far made indicate, beyond any doubt, that far greater loads are imposed upon the roll necks than have been empirically determined upon in the past.

No one will question the statement that while the necks and brasses in the plain bearing mills of today are taking greater loads than they were designed for, the fact is reflected only in the extra brass upkeep cost that is merely added to the overall rolling charge. The increase in neck breakage is probably very slight because it is very likely that the material in the rolls can take far greater loads than were originally calculated would come upon them.

In the case of roller bearings however, it would spell disaster to design a bearing for one load and then subject it to an overload of from 100% to 150% from the start. It is therefore of far greater importance that the bearing industry be given the neck loads that actually occur than it is fair to ask him to guarantee an exact figure that can be expected in the way of power savings. Such a possibility is still years away and in the interim only approximations can be made and then carefully checked when mills are in actual operation.

If you will give credence to the thought that where it has once been the practice to assume that it takes 30,000# per □" to deform hot strip, and that test has since disclosed that it actually takes from 65,000# per □" to 130,000# per □" you will agree that the question of loads bearings must take is one that cannot safetly be calculated by the old rule of thumb method.

We do not for one moment wish to evade any responsibility we should take as bearing builders. By the same token, we do not believe that the industry expects us to do anything that is, as yet, impossible. We therefore bespeak a modicum of patience on the part of the industry pledging in the meantime our assurance that we are as vitally interested in the mill bearing question as you are. In reality we are more so, for the reason, that while we are bending every effort to keep abreast of the demand, the demand, in return, continues to grow apace.

Our company has been rather reluctant in stating definitely to the industry their plans as regard the production of roll neck bearings.

We feel, however, (since the application of bearing has developed to its present magnitude) we are privileged to state that our company has already invested close to half a million dollars in heavy machinery and equipment for use exclusively in producing these large bearings, and we dare say much of this equipment was even purchased before we had any definite orders in hand, knowing, as we did, that it was only a matter of time when we would be amply compensated, in profits, for the foresight thus used.

A. I. & S. E. E. JUNIOR DIVISION

(Devoted to practical problems of electrical department employees in the Iron and Steel Industry)

REVERSING CONTROLLER WITH WESTINGHOUSE DEFINITE TIME ACCELERATING RELAYS

(Continued from July Issue)

Fig. 8 shows a simple reversing controller with definite time plugging and accelerating relays. A complete wiring diagram for a similar controller is shown in Fig. 9. The principle elements making up this controller are shunt line, directional and accelerating contactors, a low voltage protection contactor, one plugging relay to control the plugging contactor, accelerating relays to control the timing of the accelerating contactors, one two-coil overload relay, main line and control knife switch and a suitable master switch. The master switch in this case is a four point master providing four points of speed control. The operation of the controller is as follows:

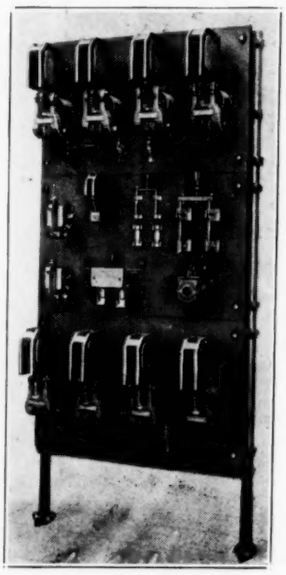

FIG. 8.

Forward: When the master switch is thrown to the forward position directional contactors 1 and 3 and line contactor 5 close completing the motor circuit through the starting resistor R_1 to R_4. Due to the current flowing in the motor circuit the movable coil PGM of the plugging relay PG and coils 12M and 13M of the accelerating relays are energized by the voltage drop in the armature and resistor steps R_1 to R_2 and R_2 to R_3 respectively. (Coil PGN of the plugging relay is a fixed shunt coil energized at all times when the control switch is closed. Coils 12N and 13N of the accelerating relays are merely demagnetizing coils, having only a few turns in series with each other and the coil of the no-voltage contactor NV. They are energized at all times when the control switch and no voltage contactor are closed). When the movable coil PGM of the plugging re-

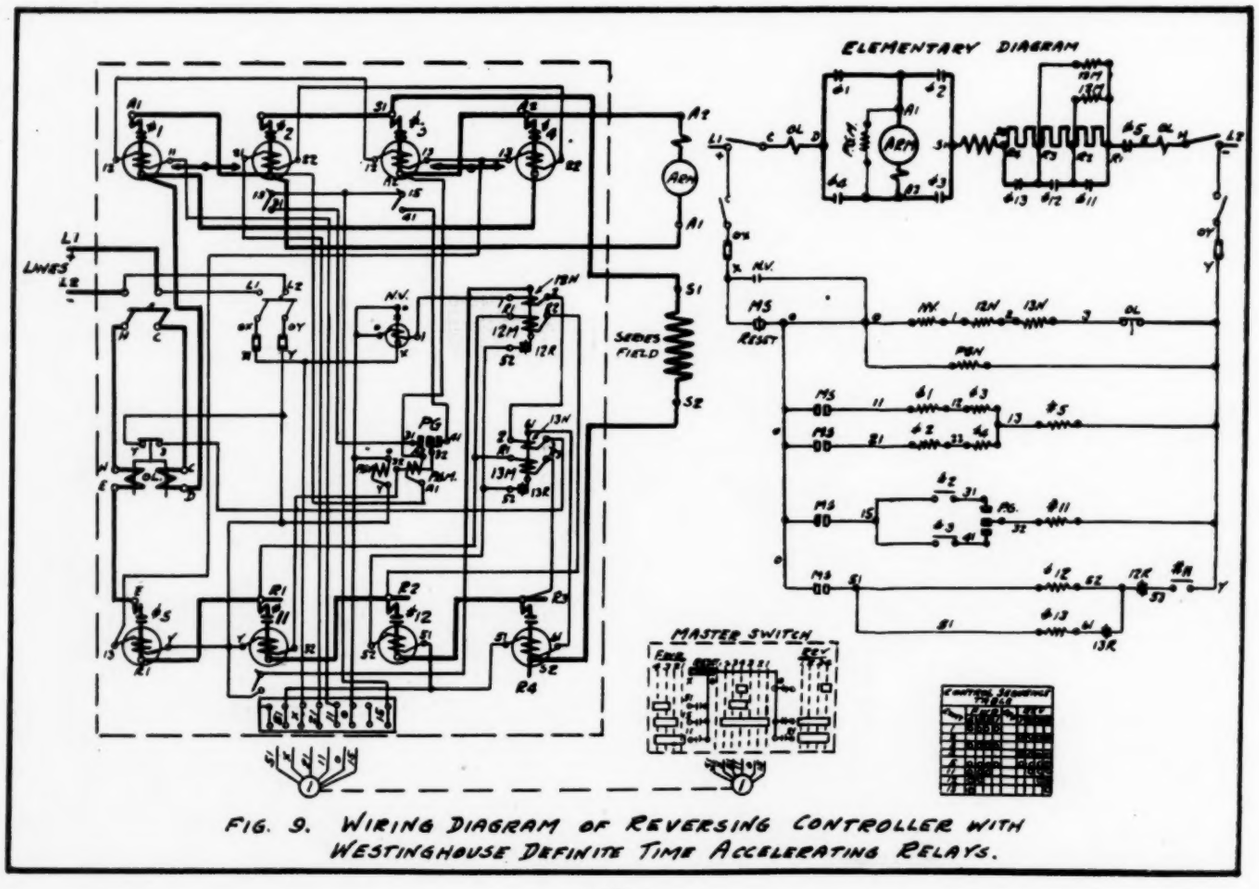

FIG. 9. WIRING DIAGRAM OF REVERSING CONTROLLER WITH WESTINGHOUSE DEFINITE TIME ACCELERATING RELAYS.

FIG. 9.

lay PG is energized it exerts a force in the permanent field of coil PGN causing it to close contacts 32—41 thereby completing the circuit for the operating coil of the first accelerating or plugging contactor 11. In closing, contactor 11 short circuits the first section R_1 to R_2 of the starting resistor and the main operating coil 12M of the first accelerating relay. The flux in relay 12M then begins to decay and, after a predetermined time, the spring pulls its armature open, closing contact 12R. Contact 12R closing completes the circuit for the operating coil of contactor 12 causing it to close and short out section R_2 to R_3 of the starting resistor and the main coil 13M of the second accelerating relay. The action of relay 13M is the same as that of 12M and contactor 13 closes after a definite time shorting out the last step R_3 to R_4 of the starting resistor.

Reverse: When the master switch is thrown to the reverse position the same action takes place except contactor 2 and 4 instead of 1 and 3 close and the plugging relay closes on contacts 32-31 instead of 32-41.

Plugging: When the motor is plugged the plugging relay prevents the first accelerating contactor 11 from closing until the motor has come to rest and is ready to start in the opposite direction. The movable coil PGM being energized by the counter voltage of the armature retains its original polarity until the motor speed has decreased to such an extent that the counter voltage is less than the voltage drop which is of the opposite polarity. The polarity of the movable coil PGM reverses and reacts with the unidirectional field of coil PGN to close the opposite contact of PG. PG closing on the opposite contact completes the circuit for the operating coil of the plugging or first accelerating contactor 11 through the interlock contact on the directional contactor, 2 or 3, which is closed.

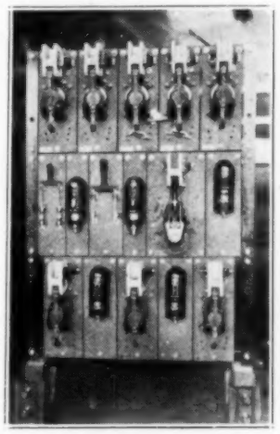

FIG. 10.

Overload Protection: In case an overload occurs in the motor circuits the overload relay OL opens, breaking the control circuit, allowing the contactors and no voltage contactor NV to open. The overload relay recloses due to gravity but the no voltage contactor remains open until the master switch is returned to the off position. A reset contact in the off position of the master switch by-passes the contacts of the no voltage contactor allowing it to close and complete its own coil circuit.

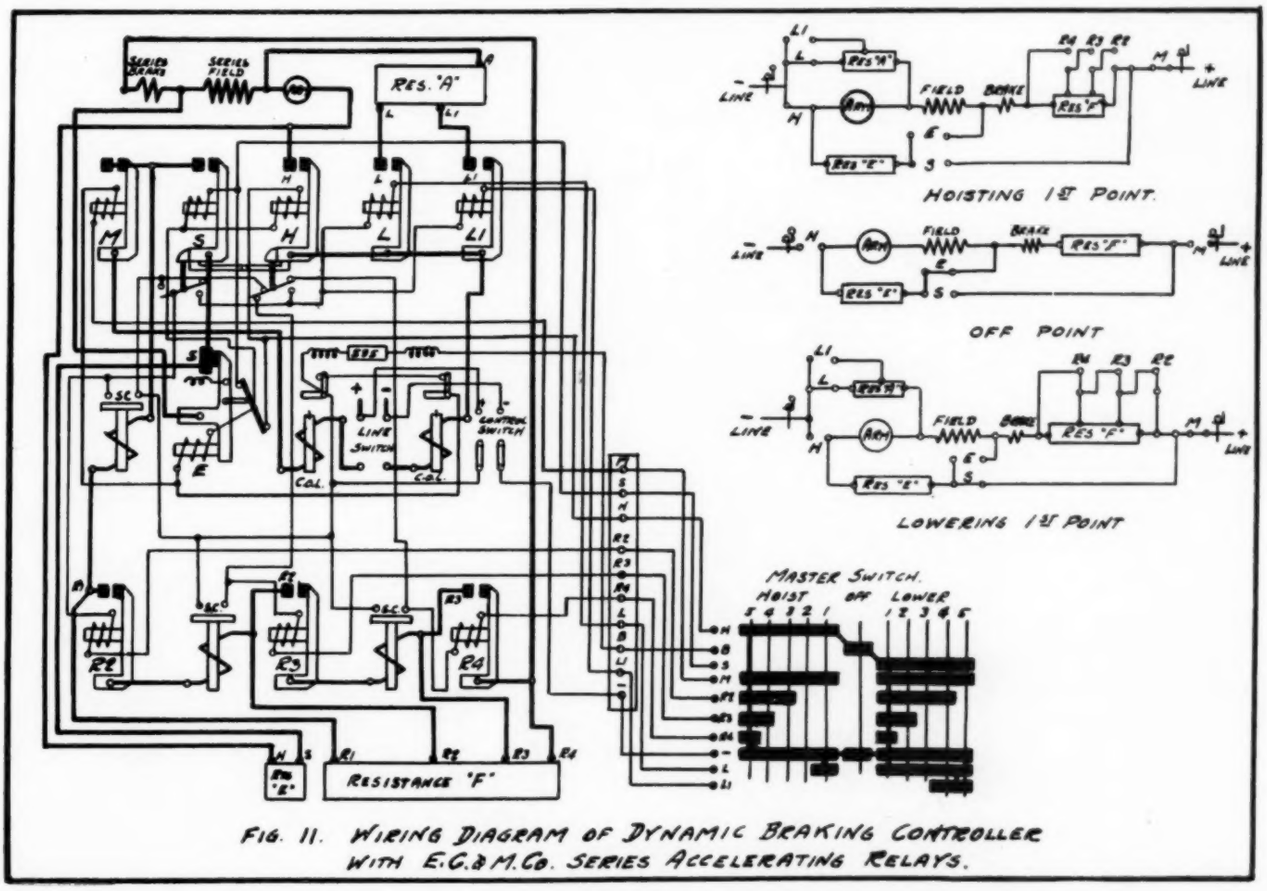

FIG. 11. WIRING DIAGRAM OF DYNAMIC BRAKING CONTROLLER WITH E.G.&M.CO. SERIES ACCELERATING RELAYS.

FIG. 11.

DYNAMIC BRAKING HOIST CONTROLLERS

Hoist controllers employing the principle of dynamic braking are made by the different manufacturers who incorporate in them the underlying principles of control, such as design of equipment and type of acceleration characteristic of their mill type controllers. Fig. 10 shows a dynamic braking hoist controller with series accelerating relays. A complete wiring diagram for this controller is shown in Fig. 11. The controller consists of shunt line, directional, accelerating and decelerating contactors, spring closed dynamic braking contactor, series accelerating relays, line and control knife switches and a suitable master switch. The master switch is a 5 point master giving 5 steps of speed control both hoisting and lowering. The operation of the controller is as follows:

Hoisting: With the master switch on the first point contactor E opens and contactors M, H and L close. Contactors M and H establish the motor circuit through the starting resistor F. Contactor L in closing shunts the armature with resistance A to give slow speed hoisting. On point 2 contactor L opens removing the armature shunt. On all succeeding points hoisting contactors R_2, R_3 and R_4 close shorting out the accelerating resistance F.

Off point: When the master switch is brought to the off position the spring closed contactor E closes, connecting resistance A across the armature and series field. The armature rotating, due to inertia or an overhauling load, acts as a generator forcing current through the resistance A. This current loads down the motor and has a strong braking effect commonly called dynamic braking.

Lowering: When the master switch is brought to the first point lowering, contactor E opens, contactors M, S and L close then R_2, R_3 and R_4 close, through control contact circuits on L and H. On point 2, R_4 opens. On point 3, R_3 opens. On point 4, L1 closes and cuts out part of resistance A and on point 5, R_2 opens. The closing of contactors M, S and L establish parallel circuits for the armature and series field. On the first point resistance A is in the line and limits the current to both the armature and field. Resistance E is in the armature circuit. Resistance F is in the field circuit but is shorted out by contactor R_2, R_3 and R_4. Thus the field strength is a maxumum and the voltage across the armature is a minimum giving the minimum speed for any load. On the second and third points sections of resistor F are inserted in the series field, thereby weakening the field and increasing the speed. On the fourth point a section of line resistor A is shorted out further increasing the speed. On the fifth and last point the remainder of resistor F is inserted in the field circuit giving minimum field strength and maximum lowering speed for any load.

Operation: With an empty hook or light loads current flows from the line into the motor driving the hoisting mechanism. With heavy overhauling loads the motor, being driven by the load, acts as a generator and returns current to the

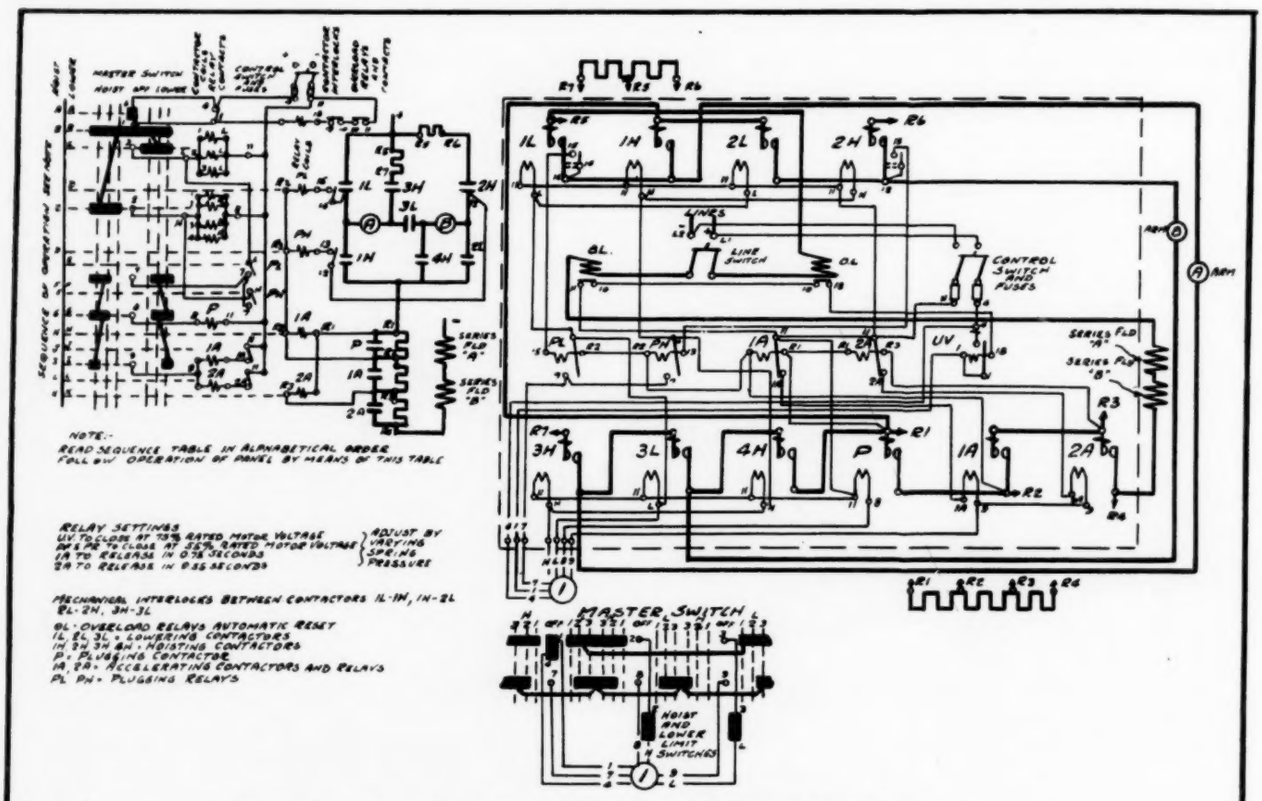
MASTER SWITCH
HOIST AND LOWER
SEQUENCE OF OPERATION SEE NOTE
NOTE:-
READ SEQUENCE TABLE IN ALPHABETICAL ORDER.
FOLLOW OPERATION OF PANEL BY MEANS OF THIS TABLE
RELAY SETTINGS
UV TO CLOSE AT 75% RATED MOTOR VOLTAGE
IA & 2A TO CLOSE AT 65% RATED MOTOR VOLTAGE
IA TO RELEASE IN 0.75 SECONDS
2A TO RELEASE IN 0.55 SECONDS
ADJUST BY VARYING SPRING PRESSURE
MECHANICAL INTERLOCKS BETWEEN CONTACTORS IL-1H, 1H-2L
2L-2H, 3H-3L
OL - OVERLOAD RELAYS AUTOMATIC RESET
1L, 2L, 3L - LOWERING CONTACTORS
1H, 2H, 3H & 4H - HOISTING CONTACTORS
P - PLUGGING CONTACTOR
1A, 2A - ACCELERATING CONTACTORS AND RELAYS
PL PH - PLUGGING RELAYS
LINE SWITCH
CONTROL SWITCH AND FUSES
SERIES FLD "A"
SERIES FLD "B"
HOIST AND LOWER LIMIT SWITCHES

FIG. 12. WIRING DIAGRAM OF TWO MOTOR CONTROLLER FOR SERIES-PARALLEL OPERATION.

FIG. 12.

line. This generator action produces the braking action commonly known as dynamic braking.

Overload Protection: In case an overload occurs the overload relays C.O.L. open, breaking the control circuit and allowing all contactors except E to drop out. Contactor E, which is spring closed and magnetically opened, closes shunting the motor with resistance A the same as in the off position of the master switch.

TWO MOTOR CONTROLLER FOR SERIES-PARALLEL OPERATION

It is not uncommon to find two motors, mechanically connected together, driving a single unit. Where it is desired to operate the motors in parallel two control panels with a single master switch, or a single control panel with balancing resistance for each motor are usually used. Where the motors operate in series a single controller serving the two motors as one motor is used. Often, however, it is desirable to have the motors operate in parallel in one direction and in series in the opposite direction. For such operation a slightly different control is required. Fig. 12 shows a wiring diagram for series-parallel operation of a two motor drive such as is commonly found on large blooming roll screw-downs.

The controller illustrated consists of shunt directional and accelerating contactors, definite time plugging and accelerating relays, overload relays, under voltage relay, line and control knife switches and a suitable master switch. The master switch shown is a three-point master providing three points of speed control in both directions. The operation of the control is as follows:

Hoisting: Parallel operation is provided in the hoisting direction. On the first point contactors 1H, 2H, 3H and 4H close, establishing parallel circuits for the armatures and completing the motor circuits through the common starting resistor R_1 to R_4. Contactors 1H and 3H establish the circuit for armature A and 2H and 4H establish the circuit for armature B. Resistors R_5 to R_7 and R_5 to R_6 are balancing resistors in series with each armature to prevent unbalancing of the load during parallel operation. On the remaining points of the master switch, and subject to the time limits of plugging and accelerating relays PH, 1A and 2A, contactors P, 1A and 2A close shorting out the starting resistor R_1 to R_4.

Lowering: Straight series operation is provided in the lowering direction. On the first point contactors 1L, 2L and 3L close completing the motor circuits through armatures A and B in series and the starting resistor R_1 to R_4. Contactors 1L and 2L provide lowering connections to the armatures while contactor 3L connects the two armatures in series. The acceleration is the same as in hoisting except that plugging relay PL instead of PH governs the closing of contactor P.

Overload Protection: Overload protection is provided by the overload relays OL in each side of the line. In tripping the overload relays open the control circuit allowing the contactors to drop out and the under voltage relay UV to open. As the contacts of UV complete the circuit for its own operating coil it is necessary to return the master switch to the off position, where a reset contact is provided, before starting again.

PROTECTION OF TRANSMISSION LINES

(Continued from Page 375)

ask Mr. Lewis if lightning arresters on this tower would be likely to improve service.

It may not be generally appreciated that the construction of a long span high voltage line in steel mills along the narrow river valleys of the Pittsburgh District is not a simple proposition. The plants have been enlarged from time to time and usually all available space between the river and the nearby hills is occupied with buildings and tracks. Towers must be installed where little space can be spared. As a result, span lengths vary from a few hundred feet to several thousand. Towers are restricted in base dimensions and become unusually heavy and expensive. Long spans in many cases necessitate extremely high towers, as the circuits must clear high buildings and stacks. Furthermore, the lines cannot be straight and angles occur at nearly every tower of such magnitude that nearly every tower is a full strain structure. The cost per mile of such a line may be two or three times greater than that of a cross country public utility line of standard construction.

There is one other point which comes to mind in this discussion and that is that dirt in the steel mills is of such a character that it will not wash off insulators by driving rain or even with high pressure hose. The most successful means of cleaning insulators in steel mills has been found to be steel wool as a rubbing agent in the hands of a husky lineman. When dirt clings to the porcelain so tenaciously it seems to me that it is beside the point to talk about the designing of rain sheds so that the driving rain will splash from the upper surface of one convolution and wash out the under surface of the convolution immediately higher. What we need for steel mill duty is an insulator with a long creepage path so designed to secure uniform electrostatic stresses, and with a smaller impulse ratio than most insulators on the market. With such insulators the steel mill engineer could clean insulators less frequently and still keep leakage down to a safe amount. There would be less danger of the insulators flashing over because operating voltages would be less likely to leakage on dirty insulators. At the same time lower impulse ratios would subject the apparatus to lower values of surge voltage than would be the case if extra units of standard designs were installed as a means of improving reliability. The only way to accomplish this result at the present time is to apply the larger number of units, and reduce the impulse ratio by applying horn gaps or rings adjusted for smaller arc over distance than is standard for the insulator string selected. If there is a better solution of this problem, steel mill engineers would be glad to hear about it.

Items of Interest

VIBRATION AS RELATED TO INDUSTRIAL LIGHTING

By ALLISON J. THOMPSON*

VIBRATION presents a very real problem in industrial lighting, due to the extremely delicate structure of the light-producing filament in the incandescent lamp.

There are six characteristics, or factors involved in vibration, viz: Wave-length, intensity, frequency, rhythm, direction, and the character of the vibrating medium—each of which has its own peculiar influence or effect upon the lamp filament, either by itself or in conjunction with one or more of the other factors. So it becomes essential to safe-guard the filament with respect to each of these factors.

There are two types of vibration which are particularly destructive to the lamp filament: the first, and apparently the most common, has a short wave-length with a high intensity, producing a sharp impact, jolt or jar which breaks the lamp filament—just as it is the sharp, quick blow that shatters molasses candy.

The second type of vibration has a very short wave-length of high and rhythmic frequency—producing a molecular agitation or disturbance in the lamp filament which in time will cause it to break—just as a piece of wire may be broken by bending it back and forth a sufficient number of times.

Vibration may be defined as an intermittent and more or less rhythmic reversal of movement, along with a resultant conflict between momentum and inertia.

When a ball is projected through space, if permitted to proceed until the energy of the projecting impulse is exhausted, the ball will fall to the ground, and nothing happens. This will correspond to one wave-length from one impulse. But if in the meantime the ball should strike something which stops its flight, the remaining portion of the wave-length will be shattered into fragments, which will proceed through the opposing body, impelled by the unexpended energy of the original impulse, gradually decreasing in intensity until it is finally exhausted.

That is to say—vibration may be produced by a single blow or impact, as in the cast just described, or by the operation of a power hammer in a forge shop, jarring the ground around it, or by the impact of a falling body, by an explosion, or by any sort of impulse which jars or jolts a resisting, elastic body or supporting medium. Vibration produced by any of such means will die out as it proceeds in its course, like ripples on the water.

Or, it may be produced by a cumulative synchronism of impulses which will have the effect of augmenting the vibration, whether it be caused by a dog trotting over a more or less flexible bridge, or by a series of impacts produced by machinery in operation. Such vibration will proceed through the structure, or supporting medium, developing a momentum until it attains its maximum, and then will die out as in the first instance. The intensity and frequency of the vibration will vary with the intensity and frequency of the vibratory impulse.

When the vibrating structure adjacent to the lamp is more or less compact and rigid, as in the case of various kinds of machinery, or other equipment, this second type of vibration may develop a very short wave-length of high and rhythmic frequency, exceedingly destructive to the lamp filament. In this case, however, it is obvious that the primary cause of the breakage is the rapid bending back and forth of the lamp filament, producing an alternation of stresses, rather than any sudden, sharp reversal of movement or impact, as in the case of a jolt or jar.

Vibration, as it proceeds along its course, will change its various characteristics according to its natural reaction to the characteristics of each medium through which it happens to pass.

The harder, more rigid or elastic the opposing body the farther the vibrations will carry—as may be illustrated by striking the end of a steel pipe with a hammer, and applying the same kind of a blow to the end of a length of garden hose.

When a lamp is rigidly bracketed close to a vibrating heavy structure, such as a thick, solid wall or column of masonry or concrete, it will receive the full effect and force of whatever vibration is in the heavy structure. The vibration waves coming from such a structure naturally will be very short and will be more destructive to the lamp filament than longer wave lengths of equal intensity. That is to say—the shorter the wave-length, at a given intensity, the more readily the filament will break.

It follows that the farther the lamp can be removed from the source of vibration, and the greater the resilience of the supporting medium, the longer will be the wave-lengths and the less destructive will be the effect of the vibration upon the lamp filament.

A messenger wire is so pliable and resilient that it affords a very ideal support for a lamp, from the standpoint of protection against vibration—where that method of installation is practicable. About the only other method of protecting the filament is to insert some specially constructed, resilient element between the source of the vibration and the lamp. Many devices, known as "shock absorbers" have been developed, which more or less effectively provide this desired protection.

As the principles applying to vibration will be the same on both sides of the resilient element, it follows that the weight of the lamp fixture is quite as important as the quality and design of the resilient element in the shock absorber. That is to say, upon the principle that the heavier a body is, the stronger the vibration will have to be in order to affect it; so the heavier the lamp fixture is, the more inertia it will have with which to "back up" or resist such vibration as may leak through the resilient element, just as on the other hand, the less the lamp fixture weighs, the more it will be affected by vibration.

For this reason there should be a proper balance or proportion between the resilient element in the

*The Thompson Electric Co., Cleveland, Ohio.

shock absorber and the weight of the lamp fixture. The heavier the lamp fixture is, the larger the wire in the spring naturally must be, to give the lamp proper resilient support, and the greater will be its resistance to corrosion.

Inert stability, therefore, is a quality much to be desired in a lamp fixture, or in some element within the lamp fixture serving as a support for the lamp bulb—as in the case of a street lamp in which the bulb stands upright above the socket, with a stabilizing inner element supporting the socket and bulb within the lamp fixture.

A shock absorber should be simple in design, rugged in construction, and must be adequate for the purpose which it is to serve. There are many shock-absorbing devices on the market, but your attention will be directed to that manufactured by The Thompson Electric Company, of Cleveland, Ohio. It is exceedingly simple in design, having but four parts—a spring and three malleable castings. Aside from a screw driver there is probably nothing which will loosen the screw like vibration, and it was felt that so far as possible, they should be eliminated from the design of a shock-absorber. There is not a screw or bolt in the Thompson device; yet the parts are so interlocked in the assembly that if the spring should ever become rusty and break, it would not be possible for the lamp to fall.

The spring is of conical, or bee-hive form, permitting the coils to nest down inside of each other, thus providing a floating pivoted support for the lamp fixture, regardless of the direction of the vibration, and a maximum of movement within a minimum of vertical space. For this same reason, the spring will take care of a wide range of lamp-fixture weights.

The Thompson shock absorber is in two models of similar design, but varying in size. The smaller model (No. 80) is furnished with either a light or a heavy spring designed to give resilient support to lamp fixtures ranging in weight from 1½ lbs. to 5 lbs., and from 3 to 8 lbs., respectively. The larger model (No. 74) also has two interchangeable springs —the lighter one to support weights ranging from 5 to 12 lbs. and the heavier spring from 9 to 30 lbs., respectively.

Both models may be used either with or without the Thompson Safety Lowering Switch, or Hanger —a device which enables lamps to be lowered away from the electric circuit, so they can be cleaned frequently and thoroughly down on the ground, and without any climbing or electrical hazards.

A new line of totally enclosed, fan-cooled motors, 1 to 50 H.P., has been developed by Allis-Chalmers Manufacturing Company. In this new design, all of the active parts, such as, stator core, stator winding and the rotor, are completely enclosed, preventing contact of outside air, dirt, dust, fumes, moisture, etc., with the interior or active parts. Heat is carried away by a sufficient volume of cooling air forced around and across those parts which conduct the heat from the interior to the outer surfaces. A circumferential air jacket controls the path of cooling air. Solid cast iron bearing housings are attached to stator end heads with machined fit, which, with grease packed bearings, form a perfect end closure. Internal parts of motor are readily accessible by removal of housings. A unique feature is that in many ratings, this totally enclosed design delivers the same horsepower output as is obtained from the same frame in the standard open rating. Temperature rise is within 55°C. measured by the resistance method. The design provides for a most rugged construction with a minimum number of parts.

Natural lightning, untamed and destructive electricity that is measured in millions of horsepower and millionths of a second, has been made to write a record of itself. In the foothills of the Allegheny Mountains, near Lake Wallenpaupack, Pa., where engineers of the General Electric Company have been co-operating in experiments and investigations on the 220,000-volt transmission lines of the Pennsylvania Power & Light system for more than three years in an endeavor to ascertain the characteristics of lightning, the greatest enemy of high voltage transmission lines, a photographic record has been obtained showing the nature of a lightning stroke on transmission wires before reaching the ground. This is the first 220,000-volt line ever built in a lightning-infested territory, and the first in the world outside of California.

This picture, taken Friday noon, July 27th, the first of its kind ever made in the world, reveals a stroke on the transmission wires of approximately 2,500,000 volts. It was made automatically by a portable cathode-ray oscillograph, a high speed camera developed in the general engineering laboratory of the General Electric Company. This device can record what happens in a millionth of a second, or even a fraction of such a brief interval.

The General Electric Company, in co-operation with the Pennsylvania Power and Light Company, the Philadelphia Electric Company and the Public Service Electric and Gas Company, of New Jersey, began this study of natural lightning on transmission lines in 1925. The cathode-ray oscillograph had not been developed at that time and various types of surge recorders were used. Early this summer, engineers of the above mentioned companies with Mr. Peek, who is credited with having done more experimenting with artificial lightning than any other engineer and who recently announced an artificial flash of more than 3,500,000 volts, made an inspection of the 65-mile, 220,000-volt lines of the Pennsylvania Power and Light Company, extending from Wallenpaupack to Siegfried, and selected a location for the experimental laboratory in the hills adjoining Wallenpaupack.

Less than a week after the cathode-ray high-speed camera had been put in working order, the awaited thunderstorm arrived and the picture was taken. The negative showed that before five millionths of a second had passed the voltage wave had climbed to more than 1,500,000 volts. A local disturbance, due to an induction flash over and reflection, caused a rise to 2,500,000 volts in a fraction of a millionth of a second. This splash or ripple then died down in a millionth of a second and the wave passed to below dangerous value in about ten millionths of a second and then to zero—all in a total of 40 millionths of a second.

This particular picture is especially interesting since it shows characteristics closely in line with predictions made by F. W. Peek, Jr., in a paper

presented before the Franklin Institute in Philadelphia in September, 1924, based on his many years of experimenting with artificial lightning in the General Electric Company's high-voltage laboratory at Pittsfield, Mass.

This field laboratory was planned with the expectation of continued observations on natural lightning, with the realization that a great deal of data will be required for practical solution of lightning control on transmission systems.

Gears & Forgings, Inc., Cleveland, Ohio, announce the opening of a New York office at 149 Broadway. Mr. Presley Hamilton will be the District Representative in charge of this office.

Waldemar Dyrssen, born at Stockholm, Sweden, in 1886. Graduated from The Royal Technical University, Stockholm, as Metallurgical Engineer in 1908. Was for one year (1909) with Les Petits Fils de Francois de Wendel et Cie Alsace Lorraine as Designing Engineer in Department of Construction; three years (1910-1912) with Uddeholm Company, Sweden, as Blast Furnace and Open Hearth Superintendent; two and one-half years (1913-1915) with the Bethlehem Steel Company, Bethlehem, Pa., as Designing Engineer in the Department of Construction; with The United States Steel Corporation, 71 Broadway, New York City, as Metallurgical Engineer, 1915-1924.

During his employment in the Steel Corporation he took part in the development of the Heroult Elec-

WALDEMAR DYRSSEN

tric Furnace and metallurgical matters in general under the late W. R. Walker and Mr. J. H. Gray. In 1923 he presented a paper on "Gas Producer Practice in Steel Works" before the American Iron and Steel Institute, New York City and in 1924 a paper on "The Recovery of Waste Heat in Open Hearth Practice" before the British Iron & Steel Institute in London, England. Since 1924 to the date of his death, August 4th, 1926, he was with the Blaw-Knox Company, Pittsburgh, as Chief Engineer, Furnace Equipment Department.

An oil circuit breaker of relatively high interrupting capacity and comparatively small overall dimensions known as the type D-127 has been placed on the market by the Condit Electrical Manufacturing Corporation.

An exceptionally heavy and rugged frame construction is used throughout and double tanks are furnished, supported by heavily ribbed cradle which is in turn hung by strong bolt construction with resilient features.

The purpose of this type of construction is to absorb the mechanical shock incident to interrupting a heavy short circuit and to reduce to a minimum the hazard which usually follows the throwing of hot oil and gases emitted on heavy short circuits.

The main current carrying contacts are Condit inverted laminated brushes of special design which will withstand extremely high inrush currents. Exceptionally heavy arcing contacts are used whose large thermal absorption capacity materially reduces arcing on interruption. Until the brushes have safely parted, the arcing contacts remain firmly closed.

The D-127 oil circuit breakers are built in single units for 400, 600, 800 and 1200 amperes at 15,000 volts, 1600 amperes 7500 volts and can be furnished for single pole or multipole operation. Estimated interrupting capacity, 8000 amperes at 7500 volts.

Owing to the small space requirements of the type D-127 oil circuit breakers, they are particularly adapted for replacing present breakers inadequate to meet the interrupting requirements of a station where large breakers could not be installed without considerable change in cell construction.

THE APPLICATION OF ANTI-FRICTION BEARINGS TO ROLL AND PINION NECKS

(Continued from page IV)

5. The expense of making any installation must be justified by a saving in operating expenses.
6. It is quite evident that formulae for roll neck design is badly needed.

In order to reduce to the absolute minimum the inventory of spare bearings necessary to properly protect a group of mills, standardization of bearing dimensions should be undertaken at the earliest possible date. This standardization could well be started by establishing at the present time, diameter increment of say ¼" for the smaller sizes and ½" for the larger sizes.

In reference to the diameter of roll or pinion necks on which anti-friction bearings are mounted, it should be noted that there is no wear on the neck and therefore, its diameter remains constant throughout the entire life of the pinion or roll so that standard bearings could alway be applied. This is one of the reasons why standardization of neck diameters is not only desirable, but also entirely feasible.

It is the recommendation of this Committee that the matter of standardization of roll necks be given full consideration in next year's program, as this should be the first step in standardizing anti-friction bearings on rolling mills.